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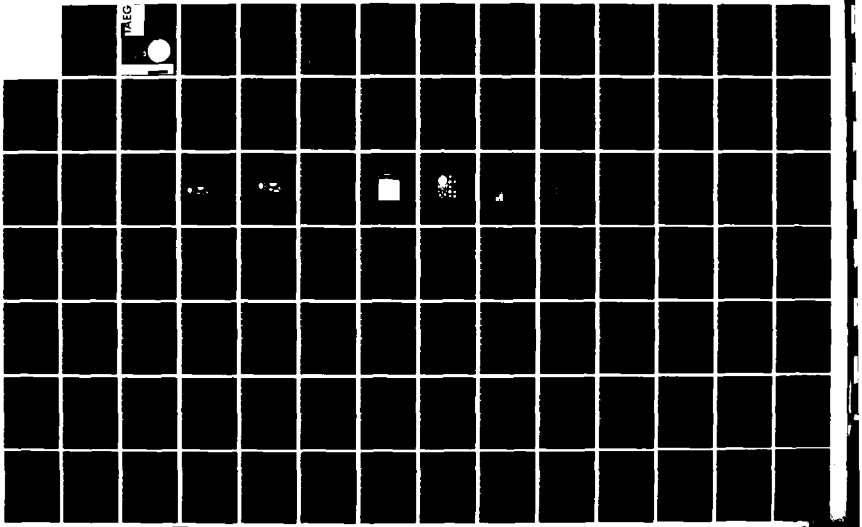

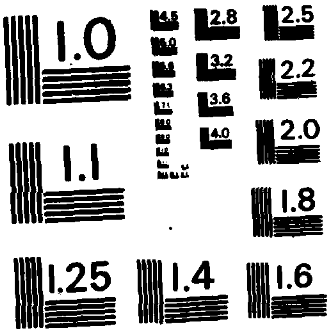

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TAEG

TRAINING ANALYSIS AND EVALUATION GROUP

TECHNICAL NOTE 11-83

(12)

# COMPUTER AIDED LAYOUT OF PROCEDURE INFORMATION FOR TRAINING AND JOB AIDING

DECEMBER 1983

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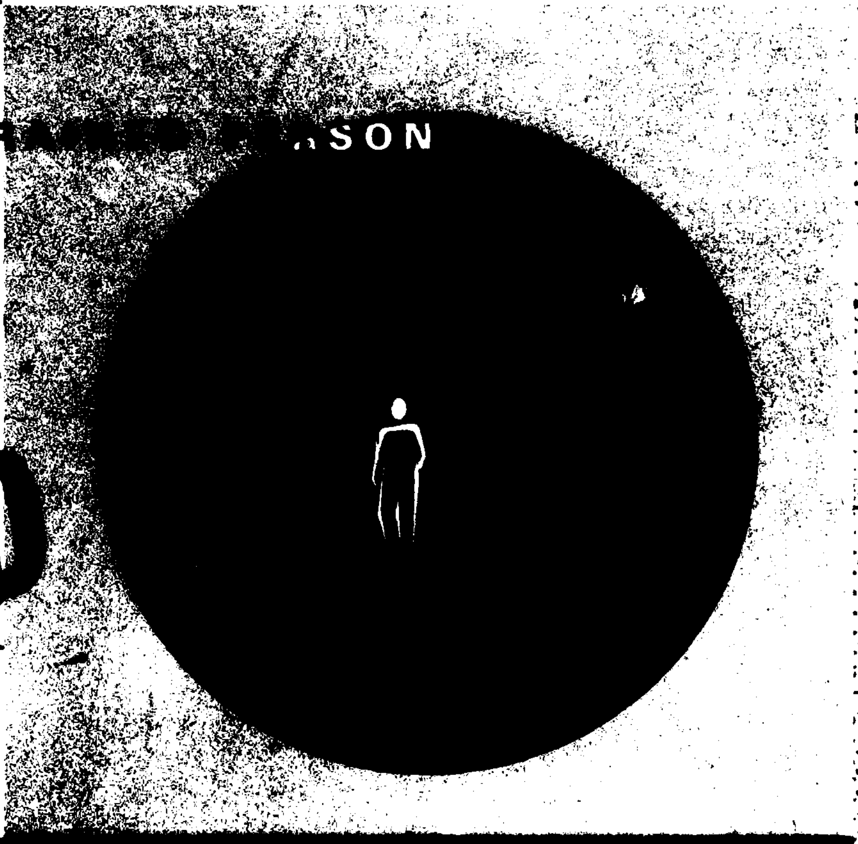

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TRAINING ANALYSIS AND EVALUATION GROUP
ORLANDO, FLORIDA 32813

Technical Note 11-83 December 1983

# COMPUTER AIDED LAYOUT OF PROCEDURE INFORMATION FOR TRAINING AND JOB AIDING

Cheickna Sylla
A. J. G. Babu
of the
State University of New York at Buffalo

Sponsored by

David W. Taylor Naval Ship Research and Development Center
Naval Technical Information Presentation Program

Approved by:

Alfred F. Smode
Director

Training Analysis and Evaluation Group
Department of the Navy
Orlando, FL 32813

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Operation and maintenance tasks for modern military systems often include long and complex procedures. These procedures must be learned and then performed from memory with the help of simple checklists or comprehensive job performance aids.

Text-graphic pages have proven to be effective in supporting a technician in learning procedures and also as aids in performing procedures.

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20. ABSTRACT (continued)

These text-graphic pages use illustrations to describe the steps in a procedure and text to clarify the meaning of the illustrations. Information that is entirely verbal is also presented with text. While text-graphic pages effectively support the performance of complex procedures, they are expensive to produce when compared with pages that are less highly illustrated.

This report describes an effort to reduce the cost of producing text-graphic pages through the use of computer routines. The main concern is automating the layout process. Within this process blocks of text and illustrations ~~are considered~~ to be rectangular objects which are related by pointers. A model was developed to optimally decompose a procedure into elements, to logically divide the elements into sets that can be displayed on individual pages, and to automatically format the rectangular objects into pages.

A heuristic was developed to handle dividing the procedure into pages and the page formatting process. The arrangement and layout problem of a single page is formulated mathematically, and a heuristic procedure based on a pairwise exchange method was developed and used to solve this problem.

The overall solution integrates these heuristics so as to mimic an intelligent human designer for the splitting of complex procedures into page sized segments and the formatting of these pages. Its development has evolved through an interdisciplinary effort of Ergonomics, traditional Industrial Engineering, and Operations Research.

## ACKNOWLEDGMENTS

This project has been successful because of the wide base of support and participation that it has enjoyed. We are indebted to the Training Analysis and Evaluation Group, Code 1 of the Naval Training Equipment Center (Dr. Alfred F. Smode, Director and Mr. Morris Middleton, Lead Engineer), which funded the study and encouraged the project in every way possible. The continual interaction with Dr. Richard Braby (of TAEG) enriched our understanding and generated deep insights into the project. We gratefully acknowledge the contributions on the human factors aspect of the project by Professor Colin G. Drury of the State University of New York at Buffalo. We are also grateful to those listed below whose courtesy, cooperation and contributions have been invaluable to this study.

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## PRECIS

The Naval Technical Information Presentation Program (NTIPP) underway at the David W. Taylor Naval Ship Research and Development Center is a large-scale effort to improve the Navy's efficiency in publishing technical information supporting the use and maintenance of equipment and systems. The NTIPP is concerned with the generation, distribution, control, and updating of technical information needed for maintenance, equipment operation, training, and logistic support. The goal of NTIPP is to define a full set of hardware support documents, including job performance aids and learning aids, and to design a computer-based system for writing, composing, illustrating, printing, distributing and updating these documents.

A major NTIPP objective is to make available computer routines to assist with the writing and formatting of information for classroom and job-site training. As part of the NTIPP effort, the Training Analysis and Evaluation Group (TAEG), Code 1 of the Naval Training Equipment Center, was tasked to design computer aids for use in authoring and formatting technical training materials. Tutorials, exercises, tests and job aids are to be automatically formatted from files of job-task data.

The present report is another in a series of TAEG documents providing NTIPP with computer routines to aid writers in creating technical training materials. It was prepared under contract (N61339-81-C-0091) by the Department of Industrial Engineering of the State University of New York at Buffalo. The report submitted by the contractor is reprinted here to ensure that the technical aspects of the development are made available to interested parties. No attempt has been made to revise or apply Navy publication standards to the report. The report describes a process called the Page Layout (PLA) system for producing text-graphic pages, a type of page found to be effective in teaching equipment operating procedures. (See Polino and Braby, 1980 and Scott, McDaniel and Braby, 1982.)

An earlier version of the text-graphic page layout system designed by Babu and Sylla (1981) was modified by TAEG (Terrell, 1982). This version of PLA is a page-oriented system in which the writer chooses the information to be displayed on a page. The writer inputs this information to a file in the computer, then the computer generates a layout and prints camera-ready copy, except that pictures and darts must be inserted by hand. One problem encountered with this version of PLA is that the writer must monitor the computer while the pages are being formatted. If the information designated for a page does not fit on that page, the writer must pull information from the page. This overflow information must then be added to the next page, changing the content of this and perhaps other follow-on pages.

The version of PLA described in this report overcomes this and other problems. Included is a page splitting algorithm which automatically resolves page overflow situations and makes it possible for the routine to format an entire document of text-graphic pages without human intervention after the initial entry is made of information to be formatted.

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The logic for a page formatting routine is described in the present report. However, the computer routines demonstrating this logic are not included. These routines are written in Fortran IV and run on a CDC Cyber 74 computer system controlled by the CDC NOS 1.4-509/552 operating system. The routines are written to demonstrate the functioning of the logic and are not designed for use by authors. A user friendly version of the routines is being prepared to run on a minicomputer and will be the subject of a forthcoming report.

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# CHAPTER I

# INTRODUCTION

Currently managers of technical information systems are being plagued by the fact it is increasingly more difficult to provide hard-copy technical manuals to meet the information needs of technicians and system operators. In 1939, a typical aircraft system required only around 500 pages of technical information (Rainey, 1978). From 1950 to 1962, aircraft complexity had increased so much that technical manual size had to be accelerated substantially. At present, a modern aircraft can require over 400,000 pages of technical manual data. This proliferation of hard copy technical information is staggering. Systems availability data on aircraft and other modern equipment indicate that technicians and operators are being overwhelmed by the mass of information. Unfortunately at the same time a serious labor crisis is taking place in the personnel system in both military and civilian sectors. Finding and retaining adequate numbers of skilled workers to operate and maintain complex equipment has become a serious national concern. The crisis is particularly acute in the military because of expanding personnel costs, among other things, and decreasing entry level skills.

The end-effects of the combination of the above two situations are substantial reduction in the complex system availability and a significant increase in the cost of ownership including a heavy front end investment cost in personnel training, which are widely discussed in the U.S. military literature. Research organizations such as the Navy Personnel Research and Development Center (NAVPERSRANDCEN) and the Air Force Human Resources

Laboratory (AFHRL) have, therefore been conducting research for the purpose of improving technical maintenance and operational data within the climate of the increasing complexity of modern equipment.

The present study is part of these programs and is concerned with the systematic presentation of the requirements and the layout of information for the learning of equipment operation and maintenance procedures in the context of technical training. Procedural activities constitute the largest percentage of involvement in most tasks of maintenance and operation of equipment. As used here, procedural activity could be executing a procedure from memory, or it could be executing a procedure with the help of simple published aids, a standard sequence of steps for the assembly, inspection, calibration, operation or service of a piece of equipment. The procedural tasks of concern in this study are of the serial type. They require relatively little judgement or analysis and a minimum of alternative behaviors. Manipulating controls is generally within the response repertoire of the students; therefore, the emphasis is placed on the correct sequencing of steps, locating components to be acted upon, positioning of knob and switches, and judging whether the equipment response to these actions is within the desired or published norms.

The present study investigates how the simple published aids can be produced more effectively. The main concern is automating the layout processing of the information when the text and illustrations/diagrams are presented in the form of rectangular objects which are related by pointers (i.e., arrows, lines ... etc.). The next three sections will present: (1) the background review of the research related to the development of procedural tasks in the context of job performance aids (JPAs) and procedure training aids (PTAs), (2) the different phases involved with the generation of the JPAs and PTAs, and (3) the detailed description of JPAs and PTAs layout problem.

## 1.1 Background Review of JPAs and PTAs

More than 20 years of research programs have given special attention to improving maintenance and operational effectiveness by improving the quality of the maintenance and operation data provided to the technician. With respect to the problems mentioned earlier, the goal has been in all programs to develop maintenance and operational data which will enable inexperienced personnel to perform maintenance and operation tasks at the level of proficiency approaching that of personnel who are experienced in performing these tasks. In 1961, in a study of behavioral analysis during task performance conducted by the AFHRL, it was concluded that "any individual can perform technical tasks without specific training, when the specific instructions are on the intellectual level of the performer and when a series of descriptive steps are given" (Foley, 1961; Foley and Munger, 1961). This result has led to the development of a type of maintenance and operation data called job performance aids (JPAs).

A substantial amount of data, collected over the past twenty years by the Army, Navy, Coast Guard, and particularly the Air Force, suggest that the job performance aids can be employed to enhance the performance of less-trained or less-skilled individuals. But more systematic methods are needed to reduce training and maintenance costs by:

1. Increasing the reliability of the performance of complex maintenance tasks.

2. Greatly improving/reducing personnel training time.
3. Decreasing dependency upon personnel of extremely high aptitude.
4. Reducing manpower requirements, and equipment down time.
5. Facilitating the transfer of maintenance personnel from one system to a different system.

Foley et al. (1971) suggested the use of Fully Proceduralized Job Performance Aids (FPJPA), based on the guidance and specification of Chenzoff et al. (1971), in an attempt to answer these needs. They are step-by-step instructions for performing any maintenance task that the technician may be assigned. The step-by-step instructions are accompanied by detailed illustrations which show the technician what the components referred to in the instructions look like and where they are located on the equipment. The aids are designed to provide the technician with all of the information, in one place, that he needs to do the job and in effect "tell him every move to make". Normally when a technician is assigned to do a task he must decide what tools to use, what actions he must take to do the job and in what sequence to perform the actions. In the development of fully proceduralized JPAs, the task analyst makes these decisions for the technician and incorporates them into the instructions. The technician does not have to generate any information himself. As a result, a less skilled, less highly trained individual can perform the job.

The general validity and acceptance of these new JPAs was mentioned in several military and civilian services reports. For example, in a study for the Army, on low-cost ownership of equipment Shriver and Hart (1975) estimated that a near 95% reduction in training time with a 60% increase in performance could be realized resulting in a global saving of $1.7 billion annually in Army personnel training and maintenance cost through the use of JPAs. In a study for the Advanced Research Projects Agency, Rowan (1973) estimated that the use of spares in electronic maintenance could be reduced by 30 percent through JPAs. The study completed for the Navy by Post and Brooks (1970) showed a 25 percent reduction in aircraft maintenance waiting time through a change in maintenance workload permitted through use of JPAs.

The development and extention of the JPAs to every aspect of technical documentation is continuing. However many questions still remain unanswered on how best to present procedural instructions. After an extensive study Booher (1975) proposed that pictures are effective in teaching location tasks but that words must also be used to effectively teach complex procedures. Guidelines have recently been published for formatting procedural instructions both for military (MIL-M-38784A; Kern et al., 1975; Ellis et al., 1979) and civilian (Hartley, 1978) applications. The U.S. Army's "new look" manuals (MIL-M-63035, MIL-M-63036, MIL-M-63038) make heavy use of illustrations and simple text which are related in an illustrative manner.

Polino and Braby (1980) used these guidelines and the learning algorithms by Aagard and Braby (1976) to create materials called Procedure Training Aids (PTAs) to teach procedures. These materials are used to teach procedures that must be performed from memory or with simple check lists instead of with job aids. Included are tasks such as many equipment operating procedures, and the use of test equipment. These procedures are used many times, must be performed quickly, and cannot be efficiently supported with job aids.

The PTAs analyze the behavioral objectives to divide the procedural steps into small parts if students are of low ability,or the procedures are complex, or the entire procedure is lengthy. Next, each task performance is presented in an observable model, and the student is directed to practice individual steps, then groups of steps, and finally the entire procedure. The procedure training aids make early training easy by making immediate and frequent use of knowledge of results and by guided and prompted responses. They help the student make the transition from a training aid to operating the actual equipment by using overview and close-up photographs or detailed line drawings of the equipment so that the student recognizes and locates the equipment, controls, and displays. Requiring the student to touch the proper place on the paper mock-up provides practice in the kinds of perceptual-motor tasks and chaining of steps required to operate the actual equipment.

The PTAs and FPJPAs are found to be significant improvements compared to older military manuals; see Polino and Braby (1980), Braby _et al_. (1981) and Foley (1978). Although potential payoffs in performance increments and cost avoidance appear to be readily available from the new JPA technologies, for the most part, JPAs are still being implemented in a piecemeal fashion by the military and civilian services (see Blanchard, 1977, Braby _et al_., 1981). Using traditional technology, the development of JPAs and PTAs is a _labor_ intensive operation; many of the tasks are still performed by hand. An author, with pencil in hand, writes all the materials that are created to support a manual of JPAs and PTAs. It should be noted that this type of writing contains a high level of redundancy (see Braby and Scott, 1980). Information is usually reformatted for different purposes. For instance, the information presented in one paragraph of a PTA may be transformed into exercises and later into test questions and answers which are repeated in various forms in quizzes and examinations. Using skilled subject matter experts and instructional technologists to carry out the laborious task of manually rearranging information is not a cost efficient alternative (Braby et al., 1976; Braby et al., 1981).

One alternative which may be efficient is to apply information processing technology to the problem to make appropriate use of computer system to reformat information for the PTAs and JPAs (see Figures 1 and 2), and automatically generate the layout of the resulting material (see Braby and Kincaid, 1981). This creates the need to design a state-of-the-art system (see Figure 3) for authoring, composing, illustrating, printing, distributing and updating these documents (see Braby et al., 1981). The computer aided layout, the subject of this study, is an essential part of this system. The type of layout problem that needs to be solved when the information in the PTAs and JPAs is presented using texts and illustrations/diagrams will be described following a discussion of the analysis and preparation involved in generating such information.

## 1.2 The Development Phases in The Preparation of The JPAs and PTAs

The JPAs evolved through several development phases to reach the formats having all the specifications which are the

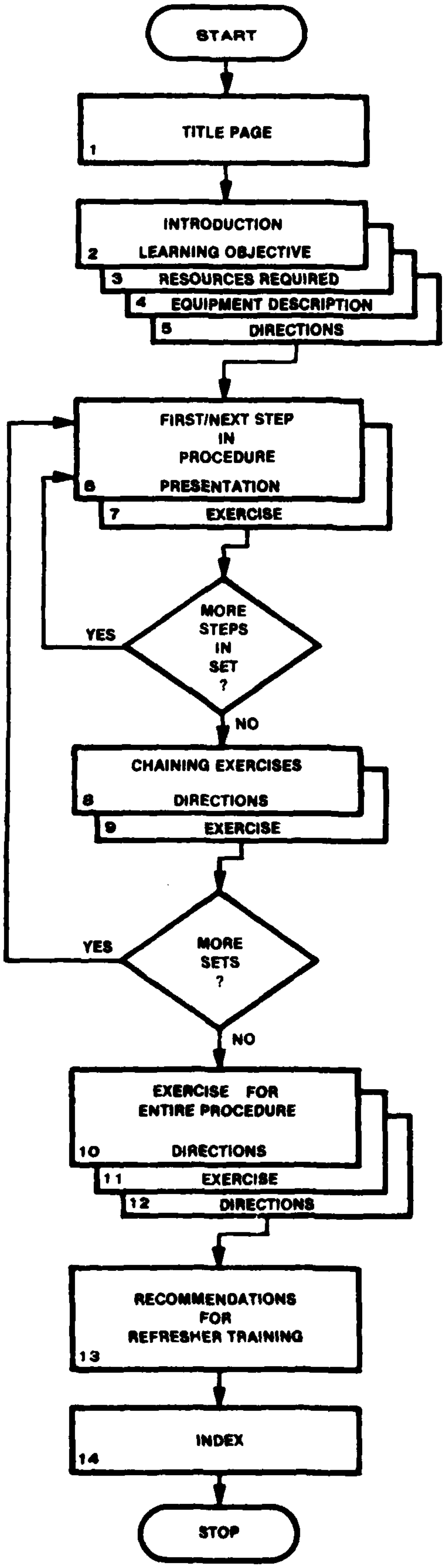


Figure 1. Sequence Diagram for Material to Teach Procedures (Adopted from Braby and Kincaid, 1981)

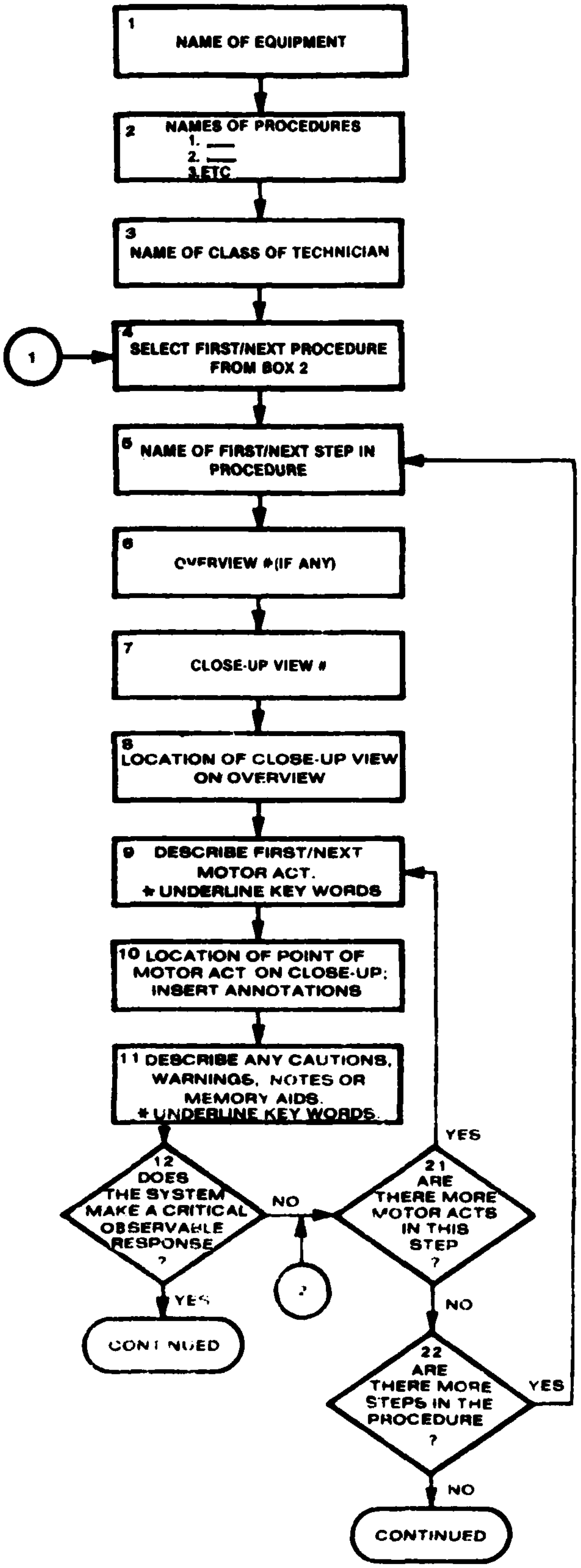

1
NAME OF EQUIPMENT
2
NAMES OF PROCEDURES
1. ___
2. ___
3.ETC
3
NAME OF CLASS OF TECHNICIAN
1
4
SELECT FIRST/NEXT PROCEDURE FROM BOX 2
5
NAME OF FIRST/NEXT STEP IN PROCEDURE
6
OVERVIEW #(IF ANY)
7
CLOSE-UP VIEW #
8
LOCATION OF CLOSE-UP VIEW ON OVERVIEW
9
DESCRIBE FIRST/NEXT MOTOR ACT.
* UNDERLINE KEY WORDS
10
LOCATION OF POINT OF MOTOR ACT ON CLOSE-UP; INSERT ANNOTATIONS
11
DESCRIBE ANY CAUTIONS, WARNINGS, NOTES OR MEMORY AIDS.
* UNDERLINE KEY WORDS.
12
DOES THE SYSTEM MAKE A CRITICAL OBSERVABLE RESPONSE ?
NO
YES
CONTINUED
2
21
ARE THERE MORE MOTOR ACTS IN THIS STEP ?
YES
NO
22
ARE THERE MORE STEPS IN THE PROCEDURE ?
YES
NO
CONTINUED

Figure 2. Parts of a Routine for Building a Computer Data Base on a Set of Procedures.
(Adopted from Braby and Kincaid, 1981)

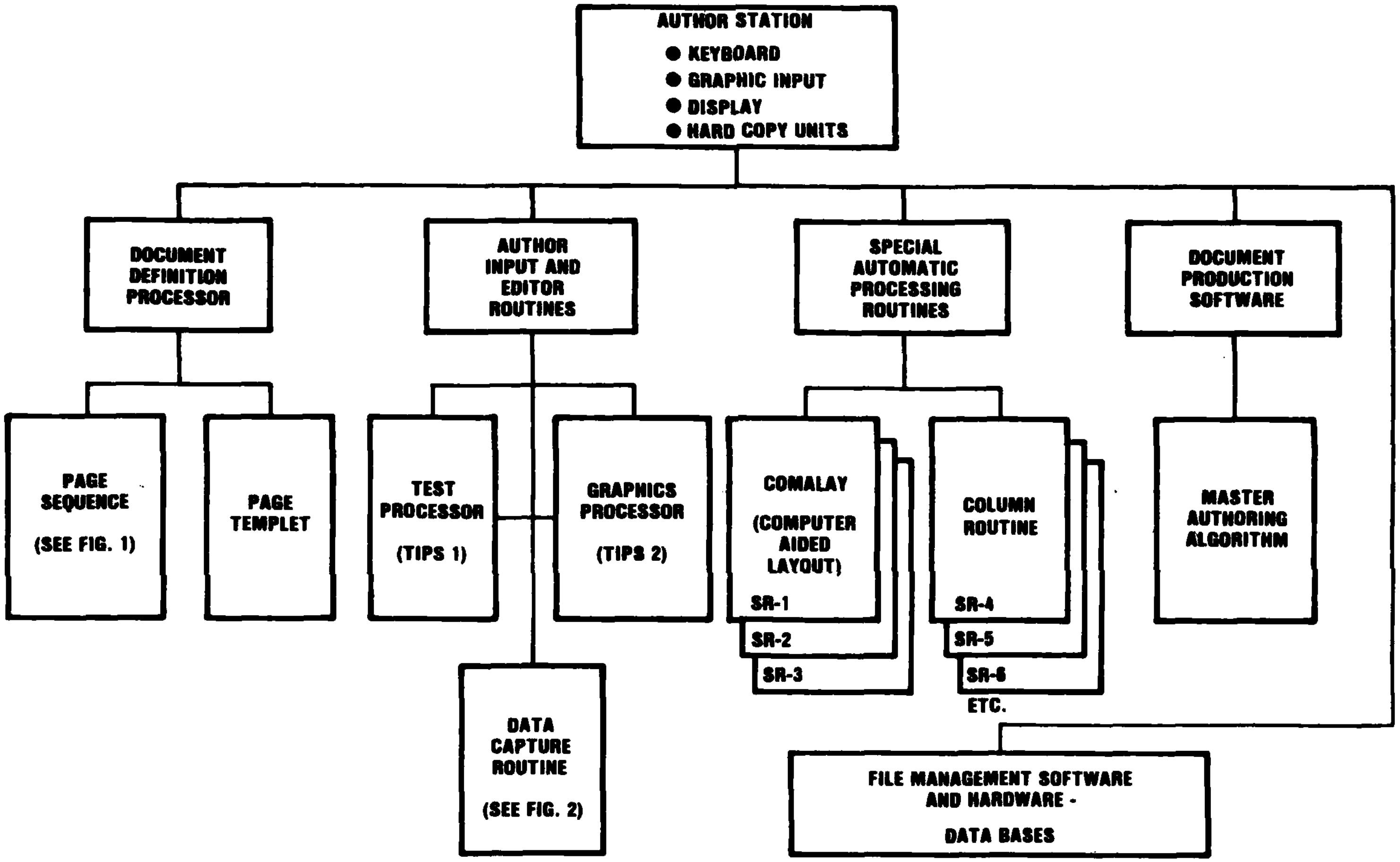

AUTHOR STATION
● KEYBOARD
● GRAPHIC INPUT
● DISPLAY
● HARD COPY UNITS
DOCUMENT DEFINITION PROCESSOR
AUTHOR INPUT AND EDITOR ROUTINES
SPECIAL AUTOMATIC PROCESSING ROUTINES
DOCUMENT PRODUCTION SOFTWARE
PAGE SEQUENCE (SEE FIG. 1)
PAGE TEMPLET
TEST PROCESSOR (TIPS 1)
GRAPHICS PROCESSOR (TIPS 2)
COMALAY (COMPUTER AIDED LAYOUT)
SR-1
SR-2
SR-3
COLUMN ROUTINE
SR-4
SR-5
SR-6
ETC.
MASTER AUTHORING ALGORITHM
DATA CAPTURE ROUTINE (SEE FIG. 2)
FILE MANAGEMENT SOFTWARE AND HARDWARE - DATA BASES

Figure 3. System Architecture
(Adopted from Braby and Cox, 1981)

subject of the present study. The same formats are also used in the PTAs. Before presenting some example formats with comments, it is appropriate to describe the essential steps of preparation. These preparation steps are equipment analysis, task analysis, behavioral task analysis and the intelligibility consideration. Because of the serial nature of the tasks involved in the JPAs and PTAs no functional analysis is included in the development phases.

## The Equipment Analysis

The equipment analysis is the earliest process of identifying all the job tasks that need to be performed on an item of equipment. The task identification or maintenance allocation is based on the equipment items, and prescribes the operator and maintenance (task) which are to be performed on each. The equipment analysis is truly a basic information chart aiming at presenting the interface between engineering and the process of developing instructions for the operator or maintenance. It insures that every major job task is identified for analysis and preparation of instructions for performing the task. It does not indicate how to perform the tasks it identifies. That is done in the following phase which is the task analysis.

## The Task Analysis

The Task Analysis identifies the conditions for performing each job task and the sub-tasks associated with each job task. The concept of Task Analysis and its related technique of Function Analysis is well presented and reviewed by Drury (1981). The purpose of Task Analysis in the JPAs and PTAs development, is to make a step-by-step comparison of the demands an operation makes on the operator with the capabilities of the operator. This analysis is identical whether it is to be used for the JPAs or the PTAs material. Figure 4 depicts the typical process involved in the analysis of maintenance tasks for JPA development. This process begins with the preparation of the task identification matrix (TIM) in (Block 1). TIM is a matrix of all equipment and items at the organizational level of the maintenance versus all type of maintenance tasks. It identifies all the theoretical possibilities at that level of maintenance. It thus tries to ensure that no tasks will be overlooked in the JPA.

A list of actual organizational level tasks (not just theoretical possibilities) is extracted from the TIM in accordance with certain criteria to form the Task Inventroy (Block 2). The task inventory is the list of tasks for which JPAs must be prepared.

Next, the initial entries are made in two special forms. The Test Equipment and Tool Use Form (Block 3) is used to standardize task-descriptive level of detail and to facilitate updating. The Supplies and Materials Form (Block 4) is an updating aid only.

The final step in the process consists of collecting many kinds of information about each task in the Task Inventory. The kinds of information required are given in detail by Folley et al., (1971). This information is either recorded on, or referenced in, the Task Description Index and Management Matrix (TDIMM) (Block 5). This document, along with all of the documents

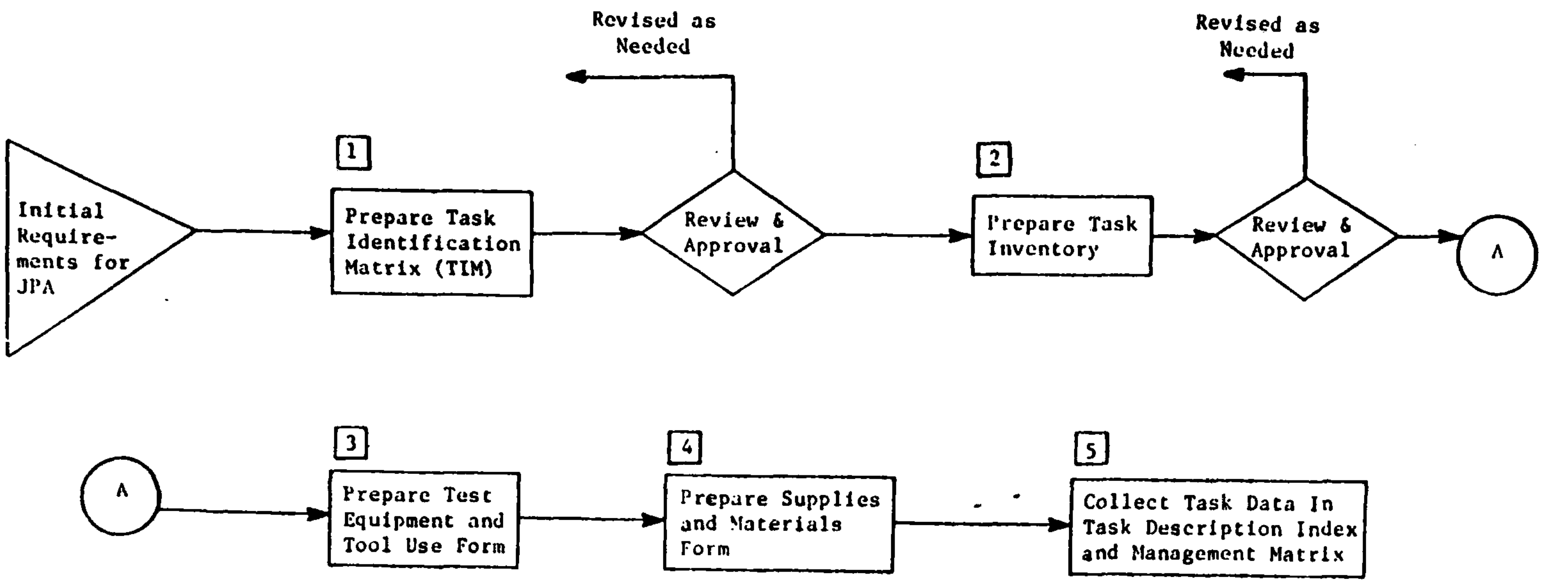

Initial Requirements for JPA
1
Prepare Task Identification Matrix (TIM)
Review & Approval
Revised as Needed
2
Prepare Task Inventory
Review & Approval
Revised as Needed
A
A
3
Prepare Test Equipment and Tool Use Form
4
Prepare Supplies and Materials Form
5
Collect Task Data In Task Description Index and Management Matrix

Figure 4. Maintenance Task Analyses Development Process

(This figure is reproduced from "Fully Proceduralized Job Performance Aids", Volume II Developer's Handbook. Foley et al., 1971).

referenced in it, provides the data base upon which all JPA elements are built.

## Behavioral Task Analysis (BTA)

The Behavioral Task Analysis involves an analysis of cues and responses used primarily to prepare graphics, but also to make the written material match the graphics. It requires the analysts to perform the tasks on the equipment. The performance is the subject of analysis, not the equipment. The final manuals contain graphic and written instructions for performing the tasks analyzed by the BTA. The materials are derived to be intelligible to novice performers. If not found intelligible, they are changed and tested again. Even if the equipment changes before the final technical manual is produced, these validations must be performed for intelligibility during development.

## Intelligibility

This element involves two parts: graphic and written. These parts are applied during the Behavioral Task Analysis cited above. The intelligibility is not another form of analysis but is rather a standard used in conjunction with the analyses. The written and graphic aspects of the intelligibility are integrated.

Text is a fundamental element in both the JPAs and PTAs. It is concerned with the prescription of single syllable verbs, and certain sentence and model syntax for written instructions. When applied with the graphic it results in materials often found to be intelligible to users with a 9th grade reading ability.

The graphic aspect is of central importance for every instruction. However, it is virtually impossible to write a specification on the appearance of a graphic. For integrated JPAs and PTAs it is specified that a context and focus view be included on each page, and that only the detail necessary to the user to make a match between the graphic and the equipment it represents be included. There are also certain requirements about numerical indexes between the graphic and the step-by-step instructions associated with the graphics.

The intelligibility standards and the Behavioral Task Analysis are developed together at the end of the design process of the JPAs and PTAs. The end product of all the analyses on any procedure (i.e., for maintenance or training) is a series of frames (page) which include text and graphic. The graphic is specified as the source of the visual cue information. The associated text (instructions) contains the fewest words possible to supplement the graphic to describe the exact action to be taken, or the system response to these actions (task steps, results, cautions, notes ... etc.).

These frames are efficient for on-the-job use as aids for technical maintenance and operation tasks or as aids for teaching materials across a broad spectrum of training tasks (e.g., procedures, system theory and nomenclature, classifying visual objects, and the application of rules, ..., etc.). Figures 5, 6, 7, 8, 9, and 10 are format models that illustrate some examples for system description/nomenclature and procedures formats. Some of the practical guidelines used in their preparation are described alongside the formats and in Figure 11 (Braby et al., 1982).

These types of formats are particularly helpful in training tasks that are performed using such complex equipment as aircraft. Students

Figure 5
(Adopted from Braby et.al., 1982)

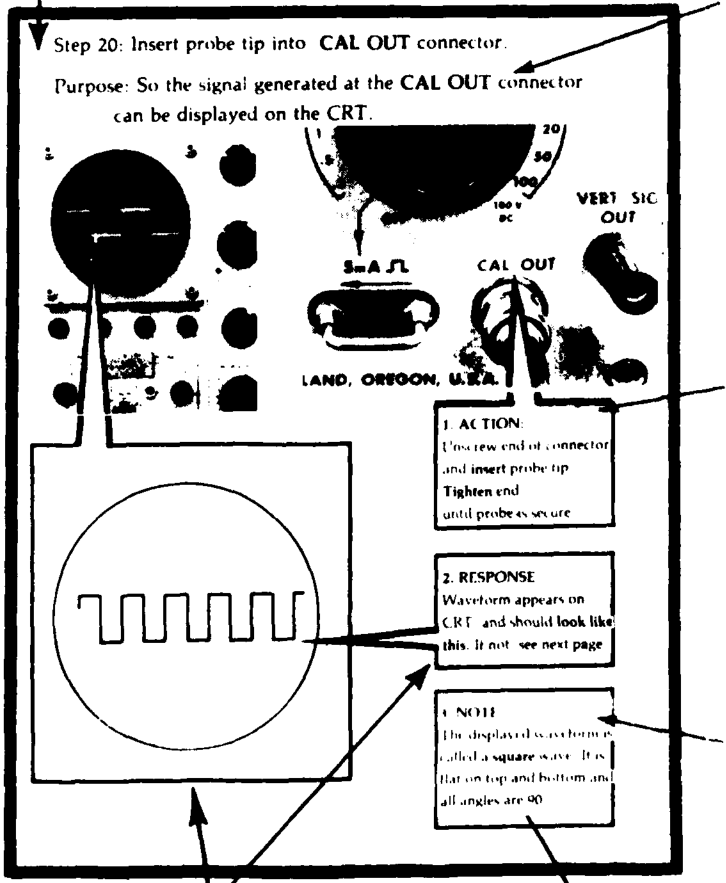
## FORMAT MODEL
## PERFORMING PROCEDURES

A general format for use in designing training materials which present steps of a procedure to be performed from memory.

Procedure Format - Page 1

Use this page format to present each step in a procedure.
The purpose of this page format is to present:
- a word description of the step—emphasize human action.
- a visual display of the step—emphasize human action.
- the purpose of the step.
- the location of actions on equipment.
- the system response to actions taken.
- notes—additional needed information.

Break procedure into logical steps.
(Each step should start on a new page.)



Step 20: Insert probe tip into **CAL OUT** connector.

Purpose: So the signal generated at the **CAL OUT** connector can be displayed on the CRT.

1. ACTION:
Unscrew end of connector and **insert** probe tip
**Tighten** end until probe is secure

2. RESPONSE
Waveform appears on CRT and should **look like this**. If not see next page

3. NOTE
The displayed waveform is called a **square** wave. It is flat on top and bottom and all angles are 90

Keep purpose short and simple.

Use line drawings or photographs.

If possible, each step should have no more than 3 or 4 actions.

State Action, and Response if there is one, and any Note. Number the boxes in the order you want them read.

Use notes to present additional information that must be recalled and used on the job.

If the system makes a response that should be noted or checked, present the response.

Underline key words

Keep pages simple, with no more than 3 or 4 boxes per page. Use additional pages if necessary.

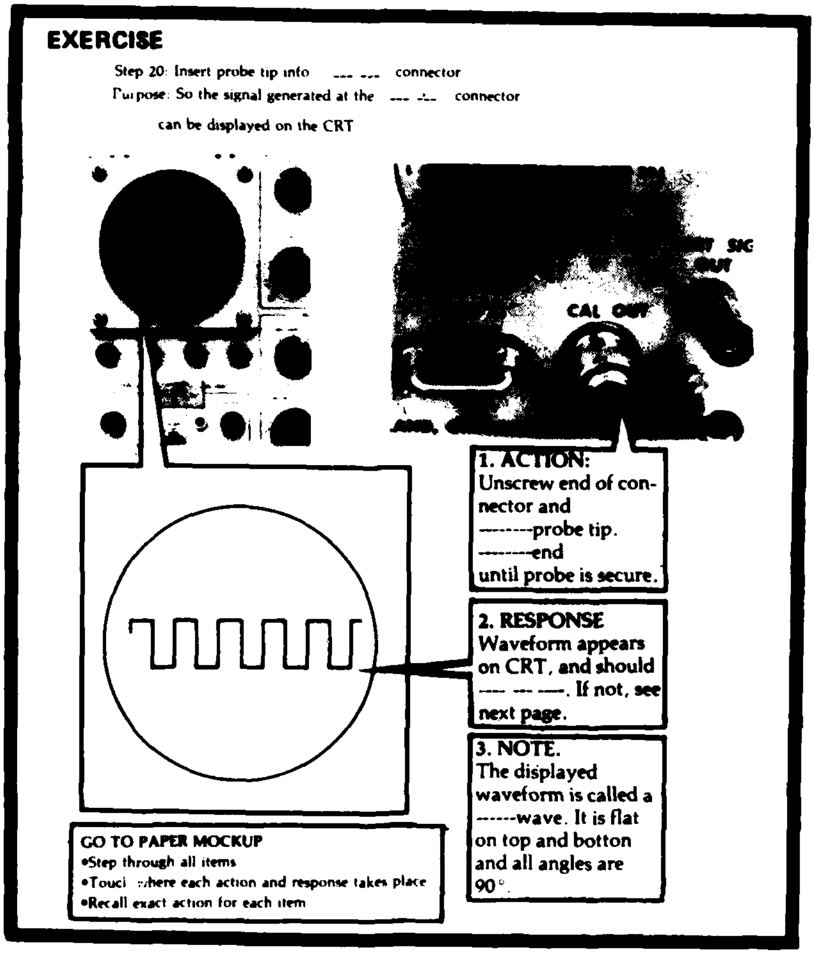
Figure 6
(Adopted from Braby et.al., 1982)

**Performing Procedures Format Model - Page 2**

Use this page format immediately following each use of the page 1 format.

The purpose of this page format is to:
- provide students exercise in the recall of key words in the procedure.
- direct the students to practice the step on the paper mock-up.

Copy the previous page. Then drop out key words that were underlined on the previous page.



**EXERCISE**

Step 20: Insert probe tip info ___ ___ connector

Pulpose: So the signal generated at the ___ ___ connector

can be displayed on the CRT

SIG
OUT
CAL OUT

1. ACTION:
Unscrew end of connector and
--------probe tip.
--------end
until probe is secure.

2. RESPONSE
Waveform appears on CRT, and should ---- --- ----. If not, see next page.

3. NOTE.
The displayed waveform is called a ------wave. It is flat on top and botton and all angles are 90°.

GO TO PAPER MOCKUP
- Step through all items
- Touci :/here each action and response takes place
- Recall exact action for each item

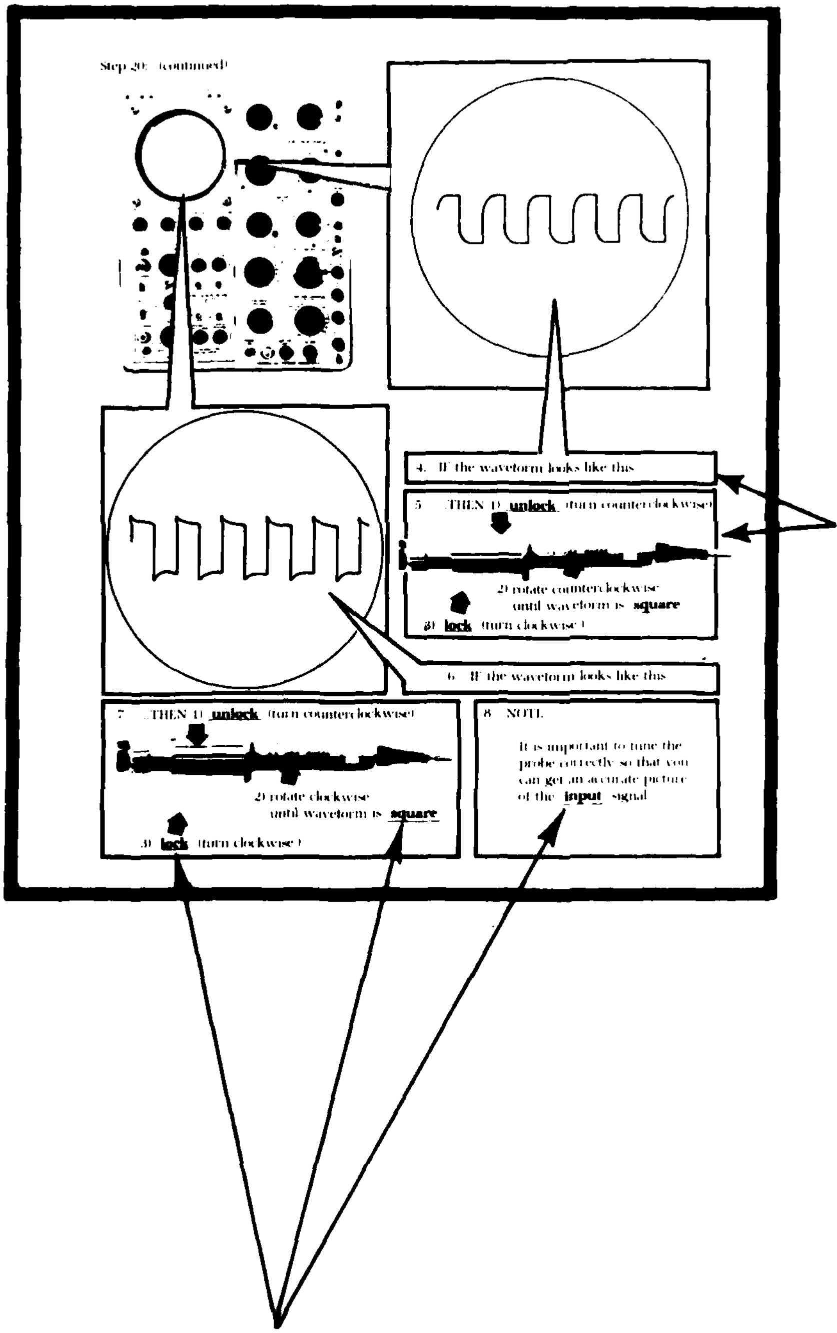
Add directions requiring students to go to the paper mock-up to practice the step.

Figure 7
(Adopted from Braby et.al., 1982)

### Performing Procedures Format Model - Page 3

Use this If/Then page to describe simple branches in a procedure.

The purpose of this page format is to:
- describe a special condition that changes the normal procedure.
- describe the action to respond to the special condition.



Step 20: (continued)

4. IF the waveform looks like this

5. THEN 1) unlock (turn counterclockwise)
2) rotate counterclockwise until waveform is square
3) lock (turn clockwise)

6. IF the waveform looks like this

7. THEN 1) unlock (turn counterclockwise)
2) rotate clockwise until waveform is square
3) lock (turn clockwise)

8. NOTE

It is important to tune the probe correctly so that you can get an accurate picture of the input signal

For any additional Responses and Actions, use the IF . . . THEN format.

Continue to underline key words.

Figure 8
(Adopted frum Braby et.al., 1982)

**Performing Procedures Format Model - Page 4**

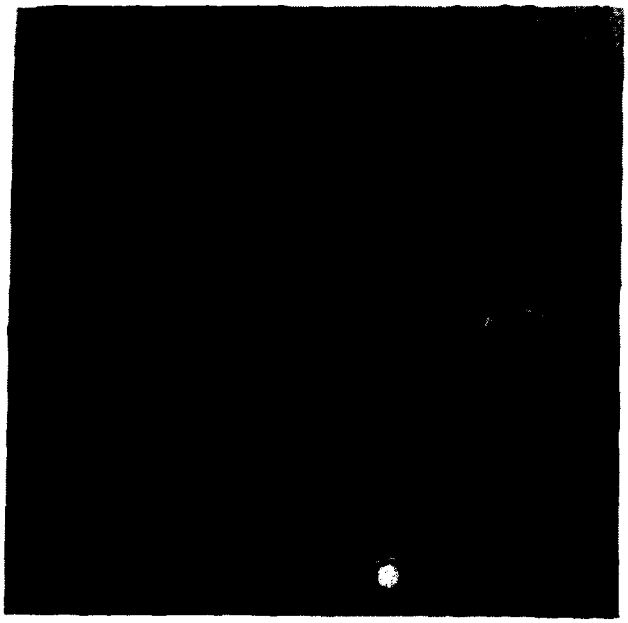
Use this page after presenting each set of 3 to 7 steps in a procedure.

The purpose of this page format is to provide a finger-tracing exercise to aid students in recalling a sequence of steps.

For each cluster of 3 to 7 steps, present a Road Map showing how the steps are chained together.

**Road Map**

- With your finger, trace the steps
- Recall (1) how to perform, (2) systems response
- Look up answers if you need help
- Keep practicing until you can describe the steps without error or hesitation.



Present last step from previous cluster.

**Go To Paper Mockup**

- Step through all items
- Touch where each action and response takes place
- Recall exact action for each item

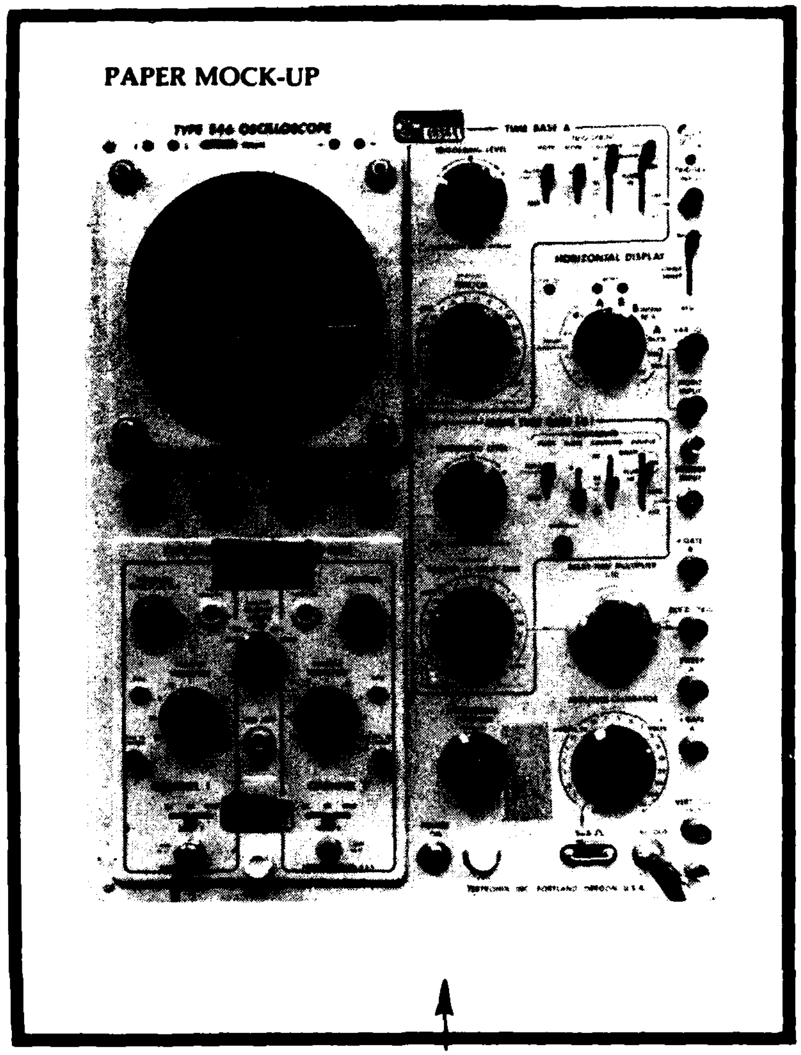
If the procedure is to be performed on the job with a checklist, present the checklist items here.

Figure 9
(Adopted from Braby et.al., 1982)

**Performing Procedures Format Model - Page 5**

Use this type of page at the end of the learning module.

The purpose of this page format is to provide students with a way to practice one step, a set of steps, or all the steps in a procedure without the use of guides and prompts.


PAPER MOCK-UP

Make sure this page is a foldout that can be used at any time.

If the procedure is to be performed on the job with a checklist, present the entire checklist here, or on the opposite page where it can be easily seen while viewing this page.

Figure 10a
(Adoptea from Braby et.al., 1982)

# FORMAT MODEL
# RECALLING FACTS ABOUT EQUIPMENT

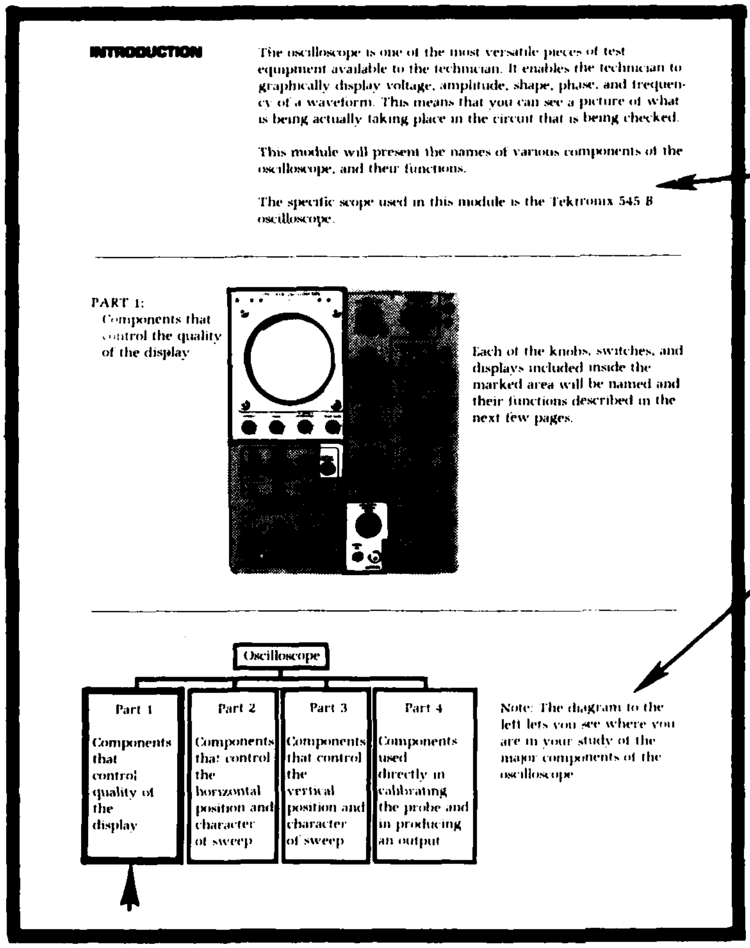
A general format for use in designing training materials to teach names, locations, and functions of the various components of a system.

---

## Recalling Facts About Equipment Format Model - Page 1

Use this page format to give an overview of the entire system or that part of the system to be described next.

The purpose of this page format is to:
- present high level system descriptions.
- name the major parts.
- point out the next part to be described in greater detail.



**INTRODUCTION**

The oscilloscope is one of the most versatile pieces of test equipment available to the technician. It enables the technician to graphically display voltage, amplitude, shape, phase, and frequency of a waveform. This means that you can see a picture of what is being actually taking place in the circuit that is being checked.

This module will present the names of various components of the oscilloscope, and their functions.

The specific scope used in this module is the Tektronix 545 B oscilloscope.

PART 1:
Components that control the quality of the display

Each of the knobs, switches, and displays included inside the marked area will be named and their functions described in the next few pages.

Oscilloscope

Part 1
Components that control quality of the display

Part 2
Components that control the horizontal position and character of sweep

Part 3
Components that control the vertical position and character of sweep

Part 4
Components used directly in calibrating the probe and in producing an output

Note: The diagram to the left lets you see where you are in your study of the major components of the oscilloscope

Put introduction on first page only

Repeat this type page for each subsystem

Describe each subsystem

Make a bold line around subsystem to be presented next

Figure 10b
(Adopted from Braby et.al., 1982)

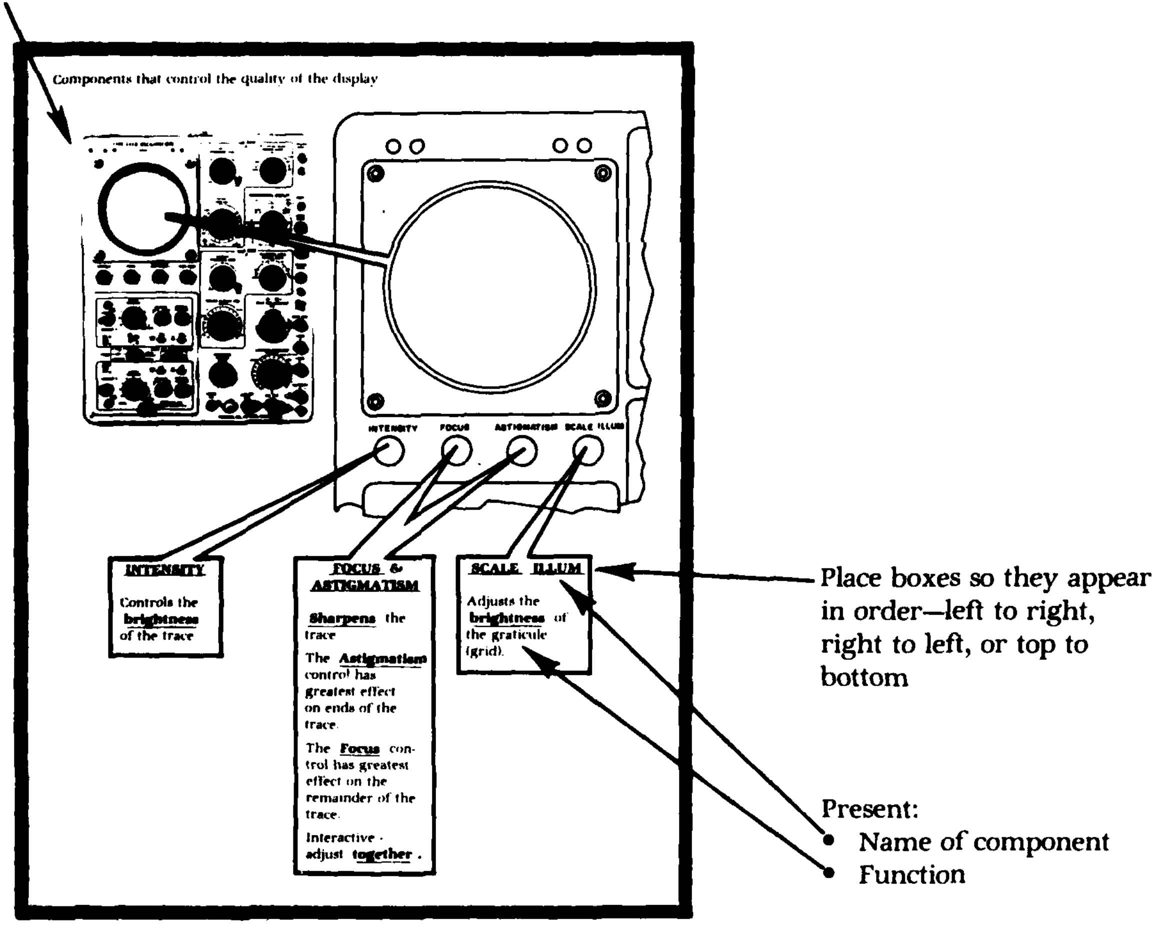
**Recalling Facts About Equipment Format Model - Page 2**

Use this page format to present information on the components of that portion of the system under discussion.

The purpose of this page format is to present the components':
- Names.
- Locations.
- Functions.

Overview should generally be in upper left hand corner of page

Point dart from close-up to general location on the overview



Components that control the quality of the display

**INTENSITY**

Controls the **brightness** of the trace

**FOCUS & ASTIGMATISM**

**Sharpens** the trace

The **Astigmatism** control has greatest effect on ends of the trace.

The **Focus** control has greatest effect on the remainder of the trace.

Interactive - adjust **together** .

**SCALE ILLUM**

Adjusts the **brightness** of the graticule (grid).

Place boxes so they appear in order—left to right, right to left, or top to bottom

Present:
- Name of component
- Function

Figure 10c
(Adopted from Braby et.al., 1982)

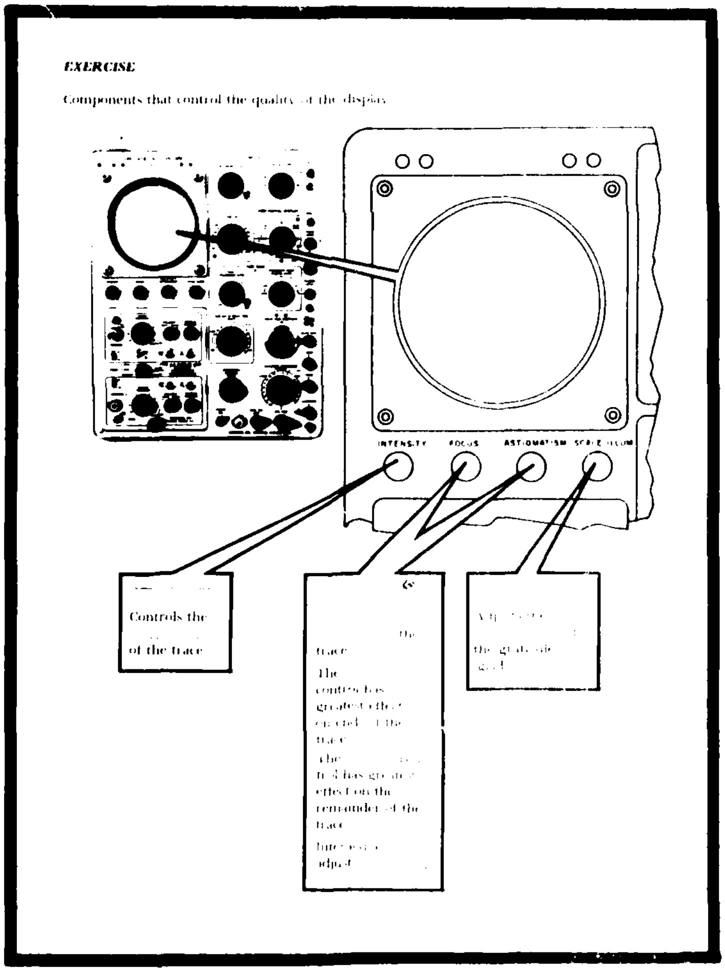
**Recalling Facts About Equipment Format Model - Page 3**

Use this page format immediately following each use of page 2 format.

The purpose of this page format is to:

- focus student attention on key words.
- provide students exercise in the recall of name, location, and function of each component when some cues are present.

Copy the previous page. Then drop out key words that were underlined on the previous page.



***EXERCISE***

Components that control the quality of the display

Controls the [illegible] of the trace

[illegible] the trace. The control has greatest effect [illegible] centred [illegible] the trace. The [illegible] control has greater effect on the remainder of the trace. Interaction adjust [illegible]

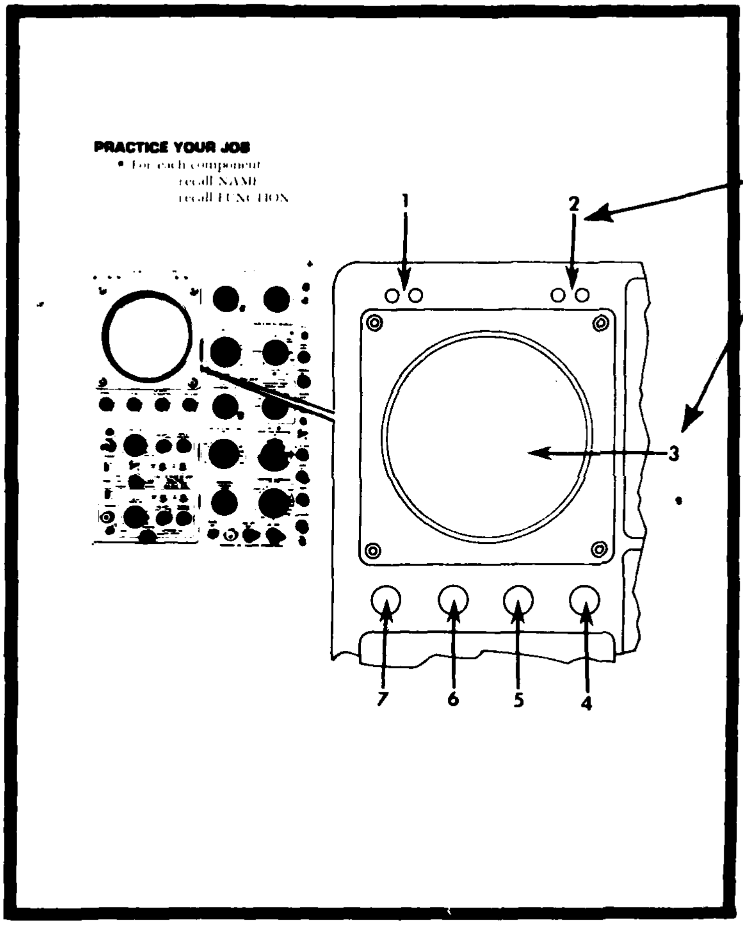
Adj [illegible] the graticule [illegible]

Figure 10d
(Adopted from Braby et.al., 1982)

### Recalling Facts About Equipment Format Model - Page 4

Use this page format immediately after presenting all the components of that part of the system under discussion or after presenting 7 components, which ever comes first.

The purpose of this page format is to provide students exercise in recalling information about the components with no verbal cues present.



PRACTICE YOUR JOB

- For each component
  recall NAME
  recall FUNCTION

Number components in a clockwise manner

Use close-ups so that the components can be easily seen

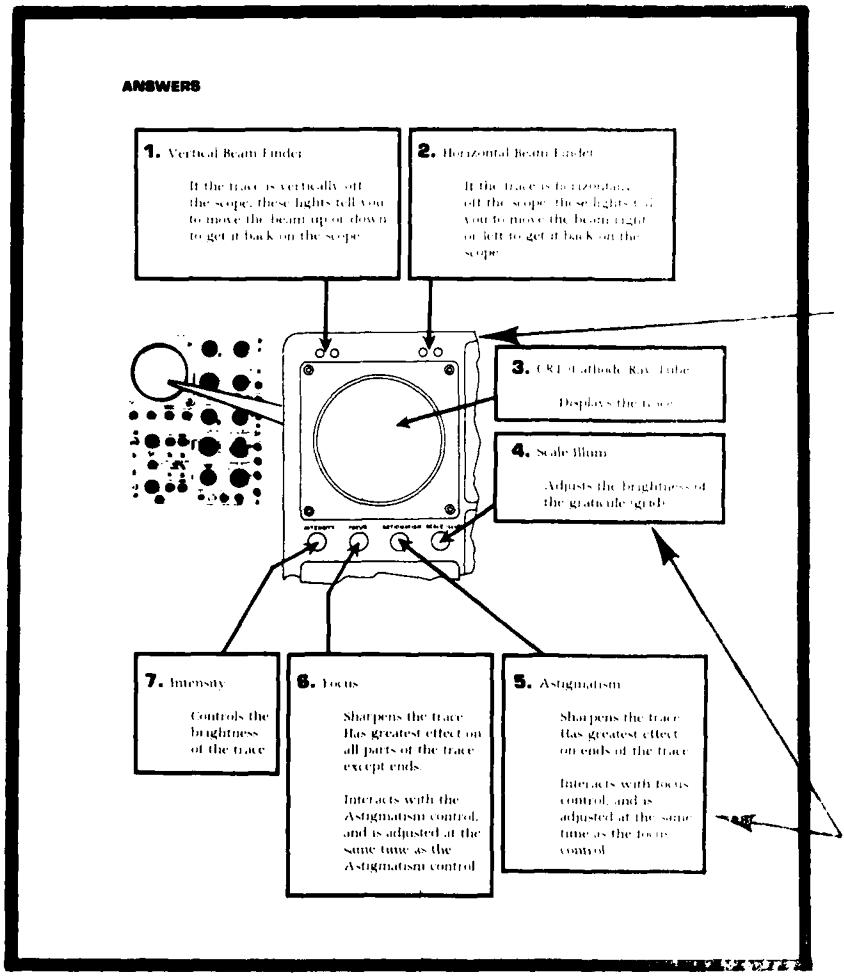
Use line drawings or photographs

Figure 10e
(Adopted from Braby et al., 1982)

**Recalling Facts About Equipment Format Model - Page 5**

Use this format immediately after each use of the page 4 format.

The purpose of this page format is to present the answers to the questions on the previous page.



**ANSWERS**

**1.** Vertical Beam Finder

If the trace is vertically off the scope, these lights tell you to move the beam up or down to get it back on the scope

**2.** Horizontal Beam Finder

If the trace is horizontally off the scope these lights tell you to move the beam right or left to get it back on the scope

**3.** CRT (Cathode Ray Tube)

Displays the trace

**4.** Scale Illum

Adjusts the brightness of the graticule (grid)

**7.** Intensity

Controls the brightness of the trace

**6.** Focus

Sharpens the trace Has greatest effect on all parts of the trace except ends.

Interacts with the Astigmatism control, and is adjusted at the same time as the Astigmatism control

**5.** Astigmatism

Sharpens the trace Has greatest effect on ends of the trace

Interacts with focus control, and is adjusted at the same time as the focus control

Reduce EXERCISE page and place against left margin

Place answers in same general area as Numbers on EXERCISE page

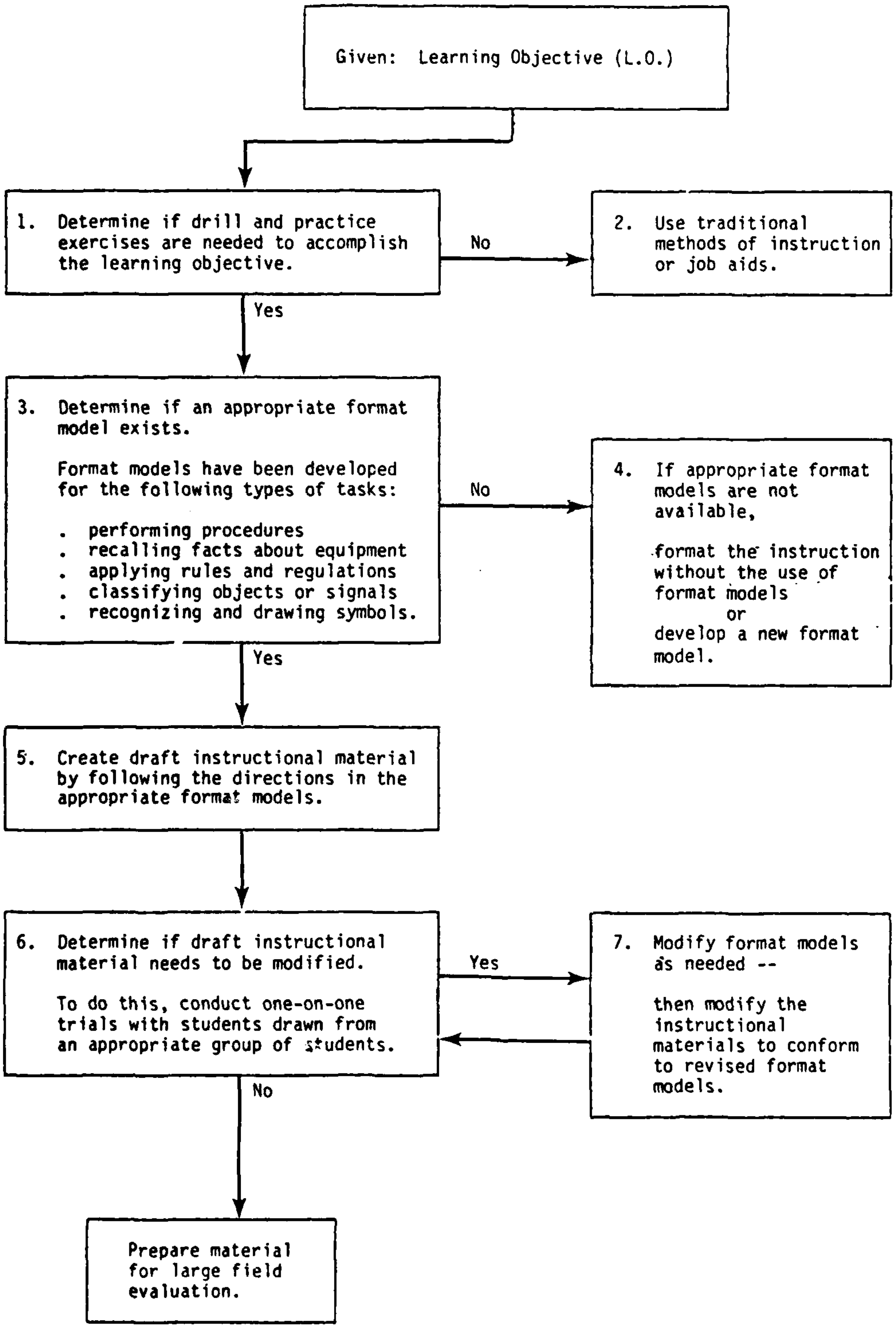

Given: Learning Objective (L.O.)
1. Determine if drill and practice exercises are needed to accomplish the learning objective.
No
2. Use traditional methods of instruction or job aids.
Yes
3. Determine if an appropriate format model exists.
Format models have been developed for the following types of tasks:
. performing procedures
. recalling facts about equipment
. applying rules and regulations
. classifying objects or signals
. recognizing and drawing symbols.
No
4. If appropriate format models are not available,
format the instruction without the use of format models
or
develop a new format model.
Yes
5. Create draft instructional material by following the directions in the appropriate format models.
6. Determine if draft instructional material needs to be modified.
To do this, conduct one-on-one trials with students drawn from an appropriate group of students.
Yes
7. Modify format models as needed --
then modify the instructional materials to conform to revised format models.
No
Prepare material for large field evaluation.

Figure 11. Steps in Using Format Models for Designing Technical Training Materials
(Adopted from Braby et al., 1982)

usually have limited access to such equipment and any training which can be efficiently completed without use of the actual equipment is highly desirable. While the learning materials using these formats were tested and found to work much better than the narrative handbooks, they are more expensive to produce than other paper manuals. Not only do they contain more pages than the traditional handbooks but they also require a considerable amount of expensive layout. For example the formats shown above were done manually and therefore large scale production of this type of page will be very expensive. Currently a comprehensive computer based publishing system is being set-up by the U.S. Navy, to meet the automated mass production of these formats at an optimal cost. This system will use computer routines to prepare camera-ready workbooks from a limited data base of text and illustrations. In support of these routines it will be possible to store photographs in digitized form, manipulate these photographs in a number of ways and merge text with the photographs; editing will be done with computer aids. For example,one will move photographs using a joystick and edit text using the keyboard. Progress to date is reported in several technical reports (Guitard, 1978; Braby _et al_., 1981; Kincaid, _et al_., 1981; Cox and Braby, 1981).

## 1.3 The JPAs and PTAs Automated Layout Problem

The present study is part of the automated publishing system described above. It aims at the optimal decomposition of the procedure steps into sub-procedures and the arrangement and layout of the elements in the frames. In this section we describe the difficulties which are encountered when arranging illustrations and text in a frame. The arrangements of illustrations and text limits the amount of information that can be presented in a single frame. The effort in the next sections is directed to creating algorithms that will optimally divide the information in the JPAs and PTAs (e.g. procedures) into sub-information (e.g., subprocedures) so as to fit into a series of single frames, and that will allow minimum interference with pointers (i.e., darts, arrows) to generate optimal layout of text and illustrations in each single frame.

In the remainder of the report the term pictures is used to refer to illustrations and diagrams, the term labels is used to refer to the text describing the tasks and the term arrows is used to refer to the pointers linking tasks to illustrations in the JPAs and PTAs.

### 1.3.1 Descriptions of Pictures and Labels

The pictures and labels are rectangular in shape and their origins are located at their top left hand corners. There are two categories of pictures used to present illustrations of the equipment in the page. The overview picture which presents the locator illustration enables the user to find the equipment items (part, switch, control, indicator, assembly, etc.) referred to in a procedural subtask. There is usually only one such picture in a page and it will be referred to as "main picture" in this study. The remaining pictures are used to show close-up views or displays of the equipment items in the main picture; arrows are drawn from these pictures to point out (end in) the respective locations in the main picture.

The labels are used to present the procedure text in steps related to the illustrations. The labels have no internal structure (points that need further close up view or display) but are linearly pre-ordered. An illustration of overview, close-up view, and label is shown in Appendix B1.

### 1.3.2 Description of an Arrangement

The spatial arrangement is defined by the sets of arrows starting from the boundaries of the pictures and/or the labels and finishing at the internal points in the pictures. An arrangement is said to be suitably implemented in a page if:

1) All the pictures and the labels are embedded in the page with no two of them (pictures and/or labels) intersecting or overlapping.

2) The sides of each picture and each label are parallel to the side of the page; the top of the picture is parallel to the top of the page.

3) The label boxes containing the text are connected to the concerned internal points of the picture-boxes by using arrows. Such an arrow starts from the boundary of a label box and ends in the concerned internal point of a picture box. It is desirable to have short straight line arrows with minimal number of intersections.

4) The labels are pre-ordered. This ordering is preserved in a layout in any convincing manner, vertically, horizontally, or any other easily readable fashion which will enhance the performance (or the learning) of the procedure while minimizing the probability of errors. Figures 5 ... 10 all illustrate the examples of a suitable arrangement, while the arrangements illustrated in Figure 12 and 13 are non-suitable.

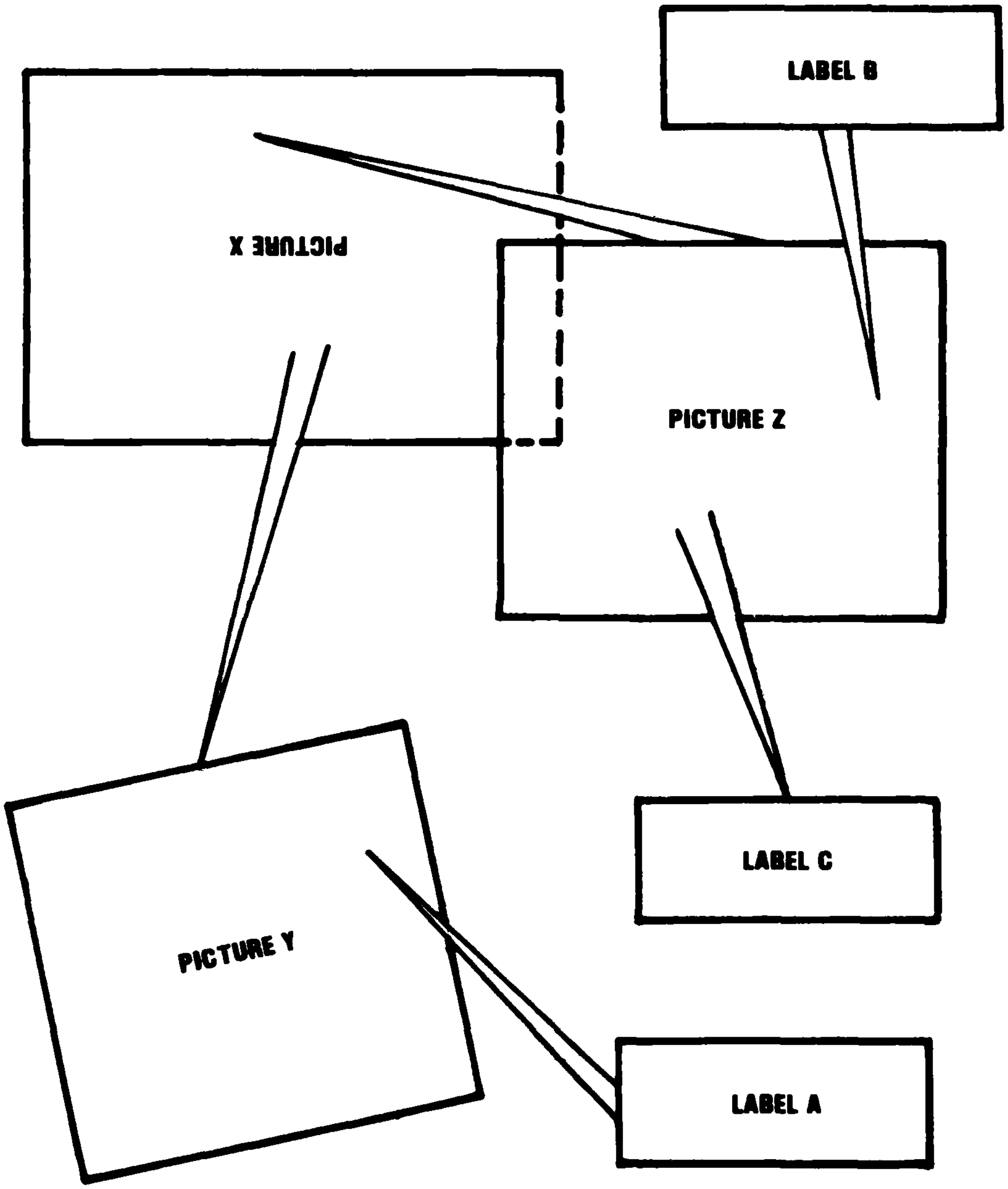


Figure 12. An example of a non-arrangement.

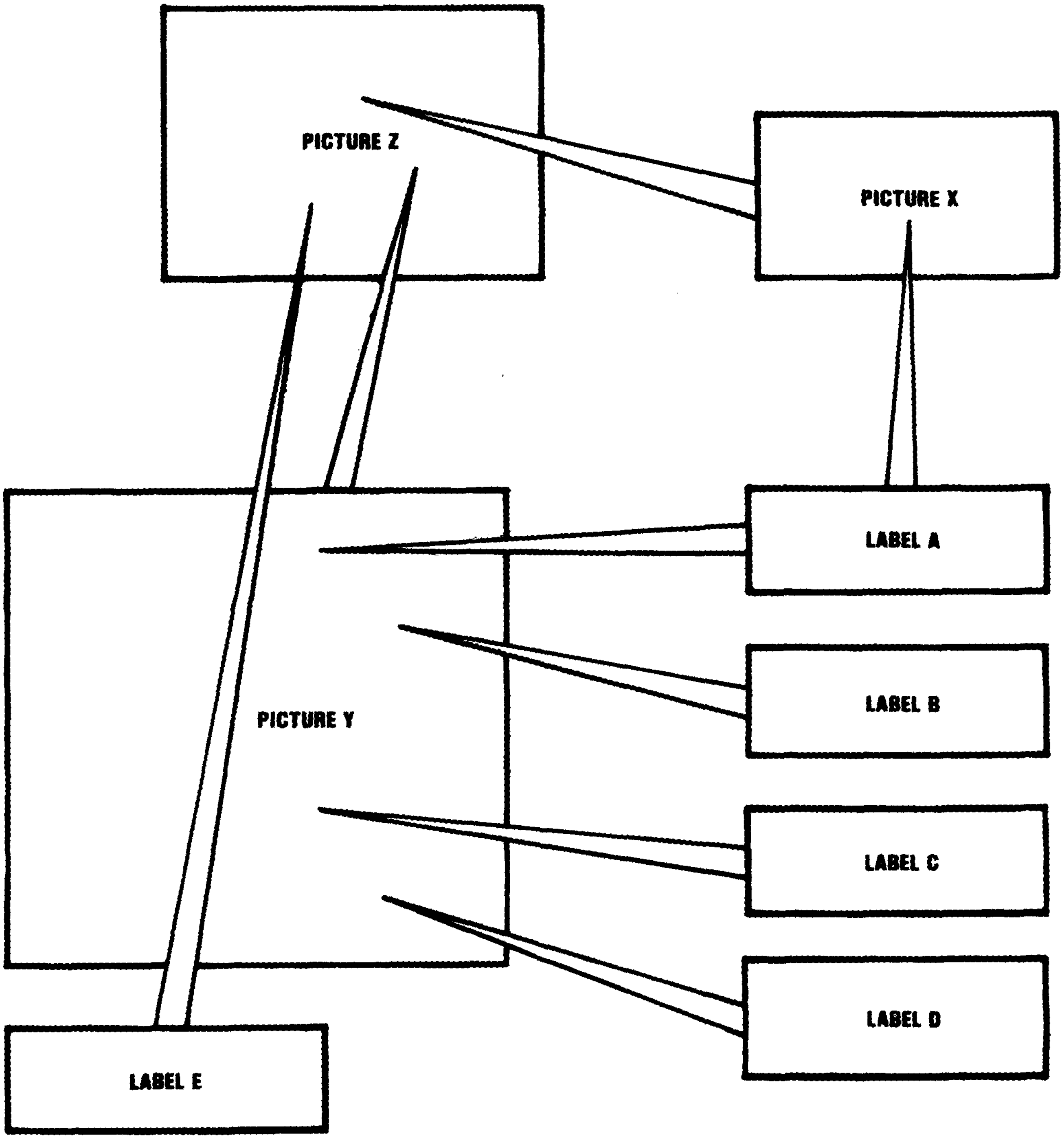


Figure 13. An example of a non-suitable arrangement

The layout problem is to find whenever possible a suitably implemented arrangement in a page with all of the above four restrictions. In addition it is preferable to keep the arrows straight and reasonably short.

## 1.4 Summary

In this chapter, the problem of the proliferation of the need for the hard copy technical manual was presented and a state-of-the-art review and an appraisal of the related literature was discussed. After showing how some twenty years of research has led to the creation and development of the JPAs and PTAs, the needs and problems involved in their mass production were highlighted; among them was the problem of finding out how to break the information into pages and the problem of laying out each of these pages. The next chapters will present the different phases involved in obtaining the solutions to these problems. Specifically, a set of algorithms and the page layout results will be presented. The development of these algorithms has evolved through an interdisciplinary effort of Ergonomics, traditional Industrial Engineering and Operations Research. In Chapter II, a detailed survey of relevant previous works in computer aided layout will be presented. Chapter III discusses the assumptions made in preparing the different phases of the solution strategy and the engineering details of these phases. Finally, the analysis of the results of the test examples of the computer runs, the discussion of the related technical information and the directions for future research are detailed in Chapter IV, V and VI.

# CHAPTER II

## PREVIOUS RELATED WORK IN COMPUTER AIDED LAYOUT

The research efforts devoted to the development of computer aided layout techniques can be divided into two major categories which are found both in the Facility Layout and the Spatial Synthesis in Computer-Aided Building design literature. The two major categories are the categories using construction type models and the categories using improvement type models. Both categories, although having some variations in approach, have the common final goal of assigning either independent or interrelated facilities to either heterogeneous or homogeneous locations. Also both use mainly heuristic type solution algorithms. The heuristic algorithms are either designed and programmed to work directly on a computer system from a set up data base or to work within close interaction with a human designer also on the system. The programs requiring interaction with a human designer during the solution process are called "interactive programs".

In what follows, the different heuristic algorithms of each category will be reviewed to evaluate the potential features in each that may make any of them suitable for use to solve the layout problem at hand. This evaluation will be made only at the end of the review of each category, that is, no effort will be made to strictly analyze each method to assess its applicability to the present problem. However, if any particular method of any category is found potentially suitable, the best algorithm (in terms of computer storage and time) using this method will be closely reexamined in the later sections. The applicability of the interactive programs as a solution strategy to the layout problem will also be evaluated.

## 2.1 Construction Type Models

### 2.1.1 Assignment Models

Koopmans and Beckmann (1957) originally formulated the problem and identified two types of facility costs. The first is the capital cost of locating any functional unit in a particular location. As each unit is likely to require particular services and those services will have a fixed initial cost of provision, this cost is defined by a metric $C_{nn}$ where there are $n$ functional units and $n$ locations. This formulation takes the form

$$\text{Minimize} \quad \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} X_{ij}$$

subject to

$$\sum_{i=1}^{n} X_{ij} = 1 \qquad j=1,2,3,\ldots,n \qquad \text{(AP)}$$

$$\sum_{j=1}^{n} X_{ij} = 1 \qquad i=1,2,3,\ldots,n$$

$$X_{ij} = 0 \text{ or } 1, \text{ for all } i,j$$

where the three conditions guarantee each functional unit being assigned to exactly one spatial unit. This is known as an assignment problem.

Haley (1962, 1963) and Pierskalla (1968) have presented a multi-index assignment problem in other contexts. Haley's three-index transportation problem formulation does not have the zero-one property in the constraint equations. There are no efficient algorithms that provide optimal solutions to multi-index assignment problems when the number of variables is large, but heuristic procedures provide satisfactory suboptimal solutions.

The second set of costs are those resulting from flows between functional units, where the relative location of the units determines the flow cost. This second cost is not a capital cost, but is repeatedly expended during each time interval of the facilities operation. In most of the literature, attention is directed to this second cost. This emphasis is consistent with the recognition that initial construction of a facility usually allows any functional unit to be placed in any location with equal cost. Such mathematical approaches, according to the basis of formulation, are called quadratic assignment or quadratic integer programming problems (QAP or QIPP). Koopmans and Beckmann (1957) also formulated this problem, and later Gilmore (1962), Lawler (1975), Land (1963), Hillier and Connors (1967), Bowman et al. (1971), Pierce and Crowston (1971), Christofides and Gerrard (1976, 1979) and Los (1978) carried out further work on quadratic assignment problems (QAP).

The general quadratic assignment problem formulation is as follows:

$$\text{Minimize} \quad \sum_{i=1}^{n} \sum_{k=1}^{n} \sum_{j=1}^{n} \sum_{h=1}^{n} C_{ikjh} X_{ik} X_{jh}$$

subject to

$$\sum_{i=1}^{n} X_{ik} = 1, \; k=1,\ldots,n$$

$$\sum_{k=1}^{n} X_{ik} = 1, \; i=1,\ldots,n \qquad \text{(QAP)}$$

$$X_{ik} = 0 \text{ or } 1, \text{ for all } i, k$$

The constant $C_{ikjh}$ denotes the cost of having facility $i$ located at site $k$ and facility $j$ located at site $h$ . The set of constraints ensures that exactly one facility is assigned to each site, and, that each facility is assigned to exactly one site.

In addition to the plant layout problem a number of other location problems can be exactly formulated as QAPs. The design of control panels to minimize the expected time required to execute a sequence of operations is one illustration of a QAP. If the sequence of operations involved the adjustment of control knob $i$ located at position $k$ , followed by the adjustment of control knob $j$ located at position $h$ , then $C_{ikjh}$ would represent the time required to go from position $k$ to position $h$ . Many additional illustrations of QAP are mentioned in the literature (see Francis and White (1974), Mirchandani and Obata (1979).

Although optimal algorithms exist for QAPs they are not feasible for problems of large size. Suboptimal (heuristic) algorithms, on the other hand, coupled with computer programs, have proved to be efficient (see Hillier and Connors, 1967). A slightly different formulation was developed by Lee and Moore (1967) in a computer program called CORELAP (COmputerized RElationship LAyout Planning). In this case, no initial allocation is provided and no enclosure defined. Whitehead and Elders (1965) have a similar computerized approach. In an industrial context, Reimert and Gambrell (1966) have devised a computer program called Flex Flow which produces schedules for the movement of machinery and equipment to process areas, rather than materials, in order to minimize materials handling cost. A mathematical approach by Francis (1967) considers finding facility designs with optimum properties and sufficient conditions for minimum total cost from the set of all possible designs. A warehouse design layout, a parking lot design and layout and a stadium design are indicated as possible applications. These sufficient properties were later used by Malette and Francis (1972) to develop the generalized assignment formulation and solution to optimal facility layout.

### 2.1.2 Graph Theory Models

The graph theoretical approach has been applied to solve the plant layout problem, see Seppanen and Moore (1970), Foulds and Robinson (1976), Christofides and Gerrard (1979) and a recent reference Nozari and Enscore (1981). These works aimed at generating the layout to minimize the total closeness rating (maximize desired adjacency) between departments. No final layout is given, and the solutions given always need some rework.

### 2.1.3 Simulation Model

The construction type models also include a simulation model called Simulation Plant Layout and Allocation of Facilities by Zoller (1970). The main components of this simulation model are a layout construction model which fits work centers of a floor space requirements in a building and the simulator which generates the sequence in which work centers are fitted. The arrangements are considered to be from a large population of feasible arrangements of work centers in a jobshop assumed to be a finite statistical population. Samples are generated from this population and are evaluated, with the objective of obtaining some observations in the vicinity of the overall optimum.

### 2.1.4 Evaluation of The Construction Type Method

As seen above, the construction type methods are used to solve mainly the plant layout problem. In doing so these methods search to find a "satisfactory" solution by employing "component approach"; see Francis and White (1974). These methods define the overall system as a collection of components or subsystems and attempts to obtain "optimum" solutions for the subsystems. However in using the "component approach" for most of the layout problems, there is a danger of developing a solution for one component that is detrimental to the overall system. This difficulty is minimized through the common use, in most of the above construction type heuristic algorithms, of materials handling cost as the most important objective. Unfortunately, the main objective of the present problem which is the "readability of a page" is of a different type. It is difficult to quantify and hence does not fall under the category of cost functions that are generally used by the construction type methods. A possible cost function to enhance the "readability of a page" includes (see details in Chapter IV): cost of violation in desired order in the arrangements of the specific labels in the layout, cost of intersections between the arrows, costs due the lengths of the arrows.

An explicit formulation of this cost function in strict mathematical sense has not been available. Indeed, even if a mathematical formulation of a cost function becomes available, when added to any possible QAP type formulation will make it extremely large and impossible to solve. Therefore it is clear that, with these peculiarities the present layout problem does not fall in the conventional area of the facility layout problems and therefore can be handled neither directly nor indirectly by the construction type algorithms mentioned above.

## 2.2 Improvement Type Methods

Improvement type methods use a series of computer programs aimed at determining up to three-dimensional layout in a building. Two well known methods CRAFT and ALDEP are discussed next.

Armour and Buffa (1963) originally presented CRAFT (Computerized Relative Allocation of Facilities Technique) which used a heuristic approach based on quadratic integer programming formulation. This orginal version was subsequently tested, refined and applied by Buffa, Armour, and Vollmann(1964) and in many other places. CRAFT is an improvement program. As such, it seeks an optimum design by making improvements in the layout in a sequential fashion. CRAFT first evaluates a given layout and then considers what the effect will be if department locations are interchanged. If improvements can be made by making pairwise exchanges, the exchange producing the greatest improvement is made. The process continues until no improvement can be made by pairwise exchanges. CRAFT requires that an initial layout be specified.

The most sophisticated systems to date following the improvement tradition are found in the area of Problem Solving (often also called Artificial Intelligence). The area of problem solving has been of interest to behavioral scientists for a considerable period of time. The range of problems examined varied from mechanical problems to puzzles and game playing. Due to the wide range of problem types that the researchers have covered, an all-encompassing theory has not evolved that would describe the problem solving activity in general terms. However the five steps of Gagne's behavioral description of problem solving (see Gagne; 1959), are generally followed by Johnson's IMAGE (1971), Pfefferkorn's DPS (1971), and Granson's GRAMPA (1970) to solve the plant and equipments layout problem. These three systems are extensively heuristic, and all solve the floor plan layout problem. While each of them use some methods to verify and satisfy the constraints, each of them is based on a predefined and limited set of criteria.

### 2.2.1 Evaluation of the Improvement Type Methods

Although no one of the improvement methods seen above addresses itself directly to the present problem, some of them have some characteristics which are found useful in the development of a solution approach to the present problem. The first such characteristic is the capability of some improvement type methods to handle problems having loosely packed type of arrangements. Also they allow the user to be able to manipulate number of parameters through which he can define his problem conditions (e.g.

constraints) and his design criteria. Finally the use of planning functions, such as, Use of Plan, Test, Reexamination, Advance Design, Redesigning are found to be very effective tools to be looked into for the solution to the present problem.

## 2.3 The Interactive Programming Approach

Most of the shortcomings in the above heuristics solution algorithm (whether from construction and improvement category) can be minimized through interaction with humans to make most of them provide good solution to the present layout problem. Indeed any heuristic without the aids, provides a limited number of courses of action where changes to the layout can be made based on the quality of the "non quantitative elements" in the cost function. Interactive programs have been successfully used for such assistance in many places (for instance see Miller et al., 1970; Matthies, 1972; Krolak et al., 1971; Gupta, 1980).

Interactive programming approach is not considered feasible for the present layout specifically due to the very large volume and variety of formats in the JPAs and PTAs manuals.

## 2.4 Summary

Previous related research in computer aided layout has resulted in many computer systems and shown in the above examples and many more are formulated elsewhere (see Moore, 1974; Francis and White, 1974). It is reported in Francis and White (1974) that no one method to date is general enough to be applied to every layout problem (floor plant, office, special objects arrangements, etc.). However, taking advantage of certain features of the QAP-formulation and tailoring the arrangement scheme using some of the ideas of the improvement type methods might provide solutions to the present problem in a reasonable time and space on a digital computer.

# CHAPTER III

# PROBLEMS RELATED TO THE PROCEDURE LAYOUT, METHODS, AND SOLUTIONS

Chapter II provides a review of the research efforts devoted to the development of various computer aided layout techniques. This review is relative to one aspect of the present study, which is the layout or arrangement problem of the objects (pictures and labels with linking arrows). No previous work specifically dealing with the splitting of lengthy procedures into subprocedures so as to fit each (i.e., arrangement of the objects in each sub-procedure) in a page, is available to date; probably due to the particular nature of this problem. Therefore, there will be no basis for comparison of the solution method to be developed here for the splitting of the procedure into sub-procedures so as to fit each sub-procedure in a page.

## 3.1 The Interaction of the two problems

The layout problem as described in detail in Section 1.3 is concerned with the arrangement of a number of objects (e.g.: $p$ number of pictures and $l$ number of labels) and some linking arrows. The objectives and constraints of this layout problem are known and specific assumptions can be made to produce a solution method for the page layout problem. However the problem of determining the number of objects that can be put in one page (a format) needsto be solved whenever the procedure is too long to fit in one page. The problem of partitioning a lengthy procedure into a series of formats $i(i=1,2,...,N)$ containing $p_i$ pictures and $l_i$ labels, so that each format $i$ fits in one page, is referred to in the remainder of this report as the "Procedure Splitting Problem". It must be pointed out that the formats i(i=1,2,...,N) are not all made up of equal numbers of pictures or labels; the number and the nature of pictures and labels are likely to differ in each format.

The splitting procedure and hence the format content depends on the following:

1) the number and the length of task steps (labels) in the procedure,
2) the natures of these task steps, the relationship between task steps, and the relationship between the task steps and pictures (diagrams) involved,
3) the natures and interrelationships of the pictures (diagrams) and,
4) the dimensions and internal contents of the pictures.

The splitting procedure is to be carried out with the additional objective of selecting elements in each split so as to make a complete and meaningful page whenever possible.

The above details indicate that the total number of pages that can result from the splitting procedure can neither be computed in advance nor before every sub-procedure split is successfully laid out in a page. That is, using any "optimal" splitting algorithm to build up pictures and labels for a sub-procedure must necessarily be followed by a validation procedure (layout) to find out how well the best arrangement of these pictures and labels will fit in a page. Hence there is a required interaction between the splitting of lengthy procedures into sub-procedures and the process of laying out these sub-procedures in pages. This required interaction can be stated as follows:

(1) The splitting process must at each stage initially determine the number of objects to go into a page,

(2) the layout process must attempt to arrange these objects successfully into a page with respect to the objectives and constraints for the good "readability" of a page.

If at any stage the layout is not feasible or satisfactory, the number of objects in the split is always reduced and a layout is attempted again until a satisfaction is obtained.

The above interaction suggests that two fundamental components are to be used to obtain pages of JPAs and PTAs whenever the number of task steps involved is too large for one page. These two components are the sub-procedure splitting process (the build up), and the layout process (the validation).

Figure 14 shows the simplified model of the layout of the procedure for a task comprising many task steps. The model includes all the major phases involved. The procedure data record updating (block 1) has the task of keeping all essential information regarding the number of objects (i.e., pictures and labels), their positions on the overview pictures and all the relationships involved. This record keeping continues until all the pictures and labels have been placed in sub-procedures by the build-up process (block 2) and successfully laid-out by the validation process (block 3). In case of an unsuccessful sub-procedure split, the validation process returns the objects in a sub-procedure back to block 2, and, a correction procedure (reconstruction) takes place, dropping one or several objects. A record updating will be carried out continuously (block 1) for the objects selected from the procedure or dropped during the reconstruction. If the sub-procedure split has successfully passed the validation phase, then the

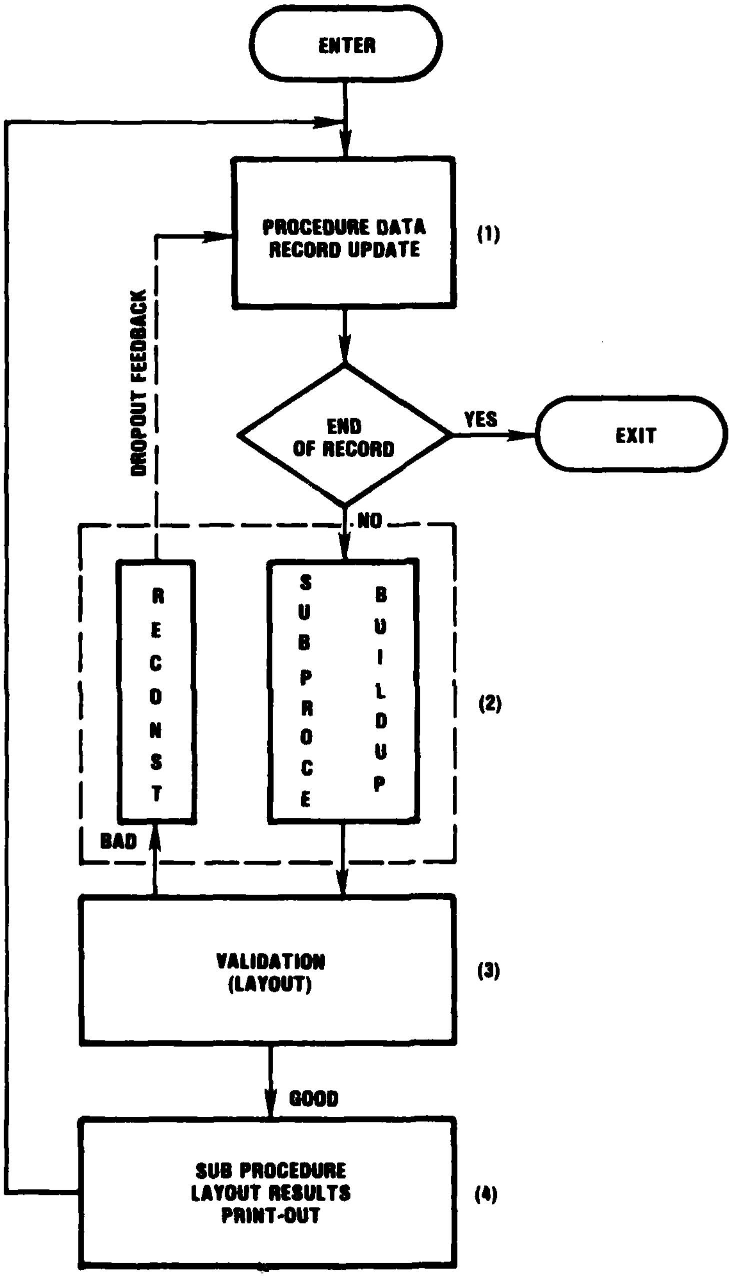


FIGURE 14. A SIMPLIFIED MODEL OF THE LAYOUTS OF LENGTHY PROCEDURE

BAD = UNSUCCESSFUL AND UNACCEPTABLE LAYOUT WITH RESPECT TO THE LAYOUT OBJECTIVES DETAILED IN NEXT CHAPTER.

GOOD = OPPOSITE

layout results will be printed out (block 4) and a return will be made back to block 1.

The remainder of this chapter is concerned with the investigations and solution algorithms dealing with the procedure splitting (build up and reconstruction) element of the JPAs and PTAs layout problem. The validation or layout procedure will be the subject of the next chapter.

## 3.2 The Procedure Splitting Problem

As mentioned in the preceding sections, a procedure may not always have a small enough number of steps to fit easily into a single page layout format. In practice a procedure will generally include many steps of maintenance, operation and/or training information and consequently, will require many task steps and accompanying pictures. Sections 1.1 and 1.2 described the main objectives of the JPAs and PTAs which are seen to be in the simplification of the maintenance, operation and/or training activities. This simplification requires breaking the task components into their simplest possible elements, therefore dramatically increasing the amount of information in a procedure. Finding an optimum split into pages can refer to either of the two following objectives of the design of the JPAs and PTAs.

(1) The "readability" objective which states that the pictures and task steps in each split (sub-procedure) must make meaningful sense together,

(2) The objective concerning optimal use of the page which requires a minimal possible number of pages be used to layout a procedure.

The nature of these two objectives and also the type of information generally contained in the JPAs and PTAs procedure clearly indicate that a solution method designed to handle the procedure splitting problem must necessarily involve some expertise in task analysis and man-machine interface consideration, and also knowledge of data base design and organization. Hence it is not feasible to find an exact solution method to split a sub-procedure optimally from the procedure with respect to all of the design considerations involved in the JPAs and PTAs development. The most that can be done for this problem is to seek a good heuristic scheme through careful investigation of rules of thumb that an intelligent and experienced human designer would use to do the splitting task. Therefore, the goal here is to find the heuristics used by human factors specialists to break lengthy procedures into sub-procedures and to devise a computerized splitting system that "behaves" like "knowledgeable people".

### 3.2.1 The Questionnaire Design

In order to find out how human factors specialists split procedures, a questionnaire was designed and submitted to a number of people knowledgeable at producing procedure training manuals. The questionnaire included three different operation procedures for a normal start checklist of an SH-3D/H Helicopter, all three procedures taken from a learning package, for pilots-in-training by Braby and Scott (1980). The full checklist is composed of 32 different procedures each presented in a continuous sequence of discrete tasks steps. Each task step in these sequences is either an Action, an explanatory Note, a Result of an action if an action causes an observable change in a system or a Caution, a Warning, a Danger, a Memory Aid or a Voice Response. Figure 15 shows a histogram of one possible interval distribution of the 32 procedures. The first interval counts the procedures having 4 task steps or less. It accounts for one half of

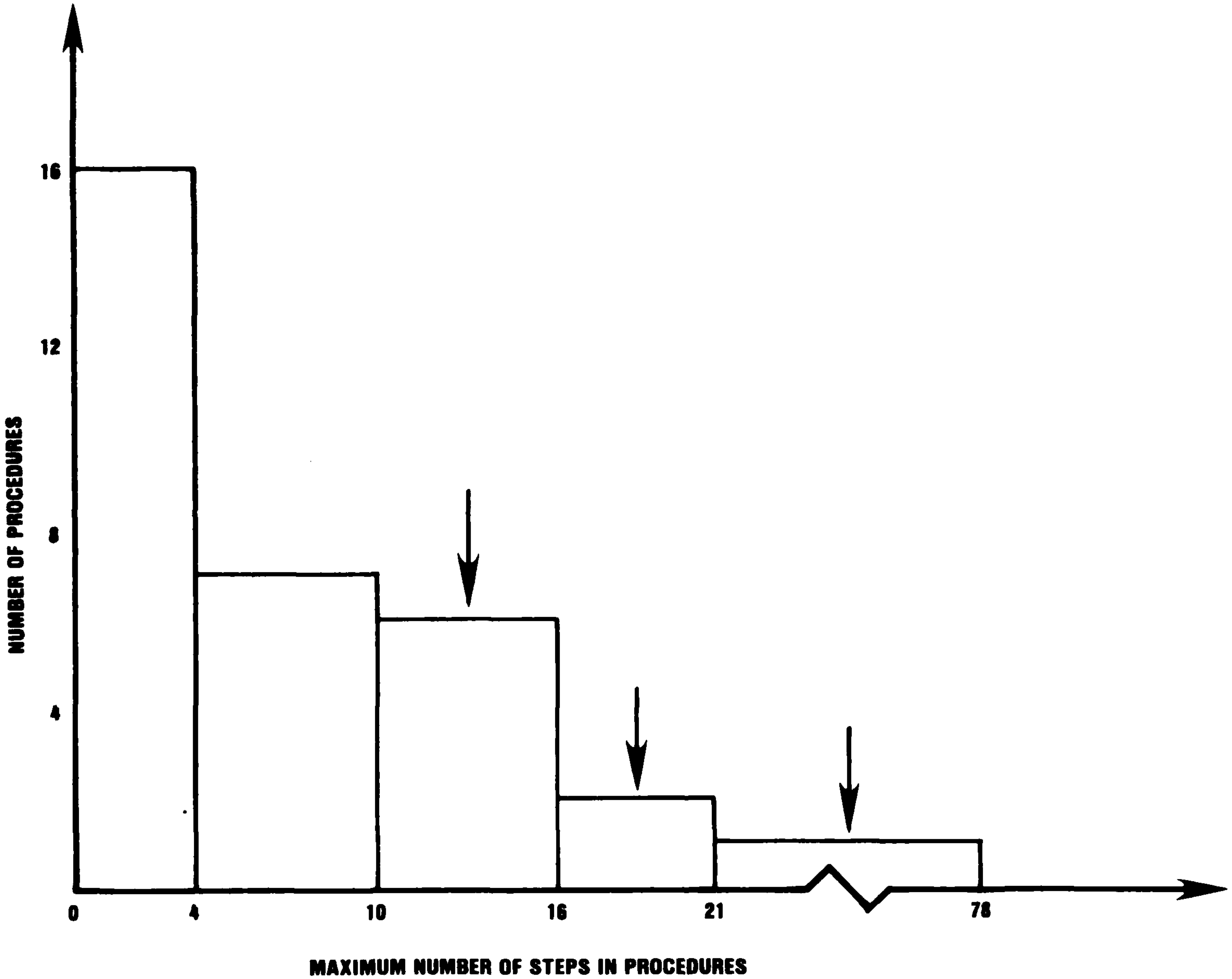


Figure 15. Histogram of Task Steps In The SH-30/H Helicopter Normal Start Checklist Procedures by Braby and Scott (1980)

the total number of procedures. These procedures are short and simple, also each can be easily accommodated into a single page. About 7 procedures in the other half include up to 10 task steps which may be accommodated in 3 pages or less. However, the procedures in the remaining three intervals are long and more complex. One representative procedure was selected in each interval to ensure that material of a reasonable but representative degree of difficulty was used.

The procedures selected were used in the questionnaire. They include:

(1) The procedure for all gages check (13 task steps and 5 pictures not including the overviews),

(2) the procedure for manual throttles and speed selector free and off check (21 task steps and 11 pictures not including the overviews),

(3) the procedure for circuit breakers and switches check (78 task stepsand 30 pictures not including the overviews).

The task steps for each procedure were pasted in a continuous string down a middle of long roll of paper. The pictures (photographs) were placed alongside the task sequence to help the participants to understand the particular procedure presented. Each task step which used a picture had a corresponding number on that picture but no arrow between task step and picture. The task steps which had no corresponding picture were also referenced. An effort was also made in the questionnaire to indicate the physical location of every picture as part of the overview near that picture. The participants were asked to use a pencil to mark the procedure at the points they would require a split, delimiting in this way the sequences (sub-procedures) which must independently fit in a page. They were also given the physical dimensions of the picture and label boxes and the page sizes involved allowing them to establish "mental limits" on the objects to go onto a page.. They were asked at the end to write-up and comment on the heuristics they had used in splitting the sequence of tasks to ensure that a sequence fits naturally onto a page. Other details about this questionnaire concerning the participants, the methodology and the pages of on- of the three task sequences used are given in Appendix A. The examination of these materials is necessary for the understanding of the analysis of the questionnaire responses in the next section.

### 3.2.2 Analysis of the responses from the questionnaire

The total number of task steps involved in all the 3 sequences was 112, and the participants analyzed and provided different numbers of total splits and different heuristic rules. Recall that the term "split" is used in here to indicate a matching set of pictures and labels, and the term "Heuristic rules" is used to indicate the particular reasons each person used to produce a split. The analysis of the responses includes the two following parts;

Part 1 to determine the maximum limits of task steps and corresponding pictures to be put onto a page from the number of splits generated.

Part 2 to determine the most important rules of thumb from the analysis of the content of the rules of the participants.

The parts are described below.

Part 1

The summary of the number of different pages generated from the split and the compositions of these pages are shown in Table 1. In the last row of this table labelled 'fraction' it can be seen that columns 1,2,3,4, and 5 together account for nearly 90% of all pages which result from the splitting of the total of 112 task steps analyzed. This fraction reaches 95% when columns 6 and 7 are added. This result suggests that, by including the types of pages in columns 1 to 7 alone one will be able to guarantee the provision of 95% of all possible types of pages which may be generated by the participants' rules of thumb based on the sample tested. Therefore it is safe to establish the maximum number of elements to go onto a page at 6 labels with up to 3 pictures or 7 labels with up to 2 pictures.

Part 2

A content analysis was done on the participants' rule of thumb. This analysis was done in the following manner:

a) Take note of every rule used by each participant.

b) Eliminate the rules which are impossible in the context of our problem, or rules which seemed to result from the participants' misunderstanding.

c) Count the frequency of the remaining rules.

These rules and corresponding frequency counts are shown in Table 2. Table 2 indicates that the splitting points mainly are decided:

1. By physical location of control (e.g., by panel),
2. By type of response (e.g., switch closure, verbal),
3. By picture referred to,
4. By system or subsystem being controlled or tested,

TABLE 1. Compositions of the Subjects Split

|  | FREQUENCY |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |  |
| Participants | 3L *<br>W* 2P* | 4L<br>WU to 2P | 3 to 4L<br>W3 to 4P | 5 to 6L<br>WU 2P | 5 to 6L<br>WU 3P | 5 to 6L<br>WU 4P | UP 7L<br>WU 2P | UP 7L<br>WU 3P | UP 7L<br>WU 4P | UP 7L<br>WU 5P | 8L<br>UP 2P | 8L<br>UP 4P | Total #<br>pages<br>(row) |
| 1 | 11 | 8 | 0 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 25 |
| 2 | 15 | 9 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31 |
| 3 | 12 | 13 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 |
| 4 | 6 | 7 | 0 | 8 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 25 |
| 5 | 2 | 4 | 0 | 5 | 4 | 1 | 3 | 1 | 1 | 0 | 0 | 1 | 22 |
| 6 | 21 | 6 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 34 |
| 7 | 9 | 6 | 1 | 6 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 27 |
| 8 | 18 | 9 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 33 |
| 9 | 8 | 8 | 1 | 6 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 25 |
| 10 | 3 | 4 | 0 | 4 | 4 | 0 | 3 | 1 | 1 | 0 | 1 | 0 | 21 |
| 11 | 9 | 15 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| 12 | 24 | 14 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 |
| 13 | 2 | 6 | 1 | 6 | 2 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 22 |
| 14 | 14 | 7 | 0 | 4 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 29 |
| Column Total | 154 | 116 | 6 | 55 | 23 | 2 | 19 | 6 | 6 | 1 | 1 | 3 | 392 |
| Fraction | .392 | .295 | .015 | .14 | .058 | 0.005 | .048 | .015 | .015 | .002 | .002 | .006 |  |

Total number of steps used (3 task sequences) = 112, number of accompanying pictures = 46**
Average number of pages of subprocedure 28
Standard deviation from mean 5.21

*Descriptors: L task step; P: picture; W: with; WU: with up to

**Not accounting the overview picture

| Rule | Frequency Count |
|---|---|
| Split by different panels | 8 |
| Split by visual/verbal response/hand movement | 6 |
| Split by system/sub-system | 5 |
| Don't split notes, voice response, etc., from reference | 4 |
| Use rows of switches or control | 4 |
| Split by same picture | 4 |
| Allow plenty of white space | 2 |
| Split by outside/inside lighting | 2 |
| End a page with a response | 2 |
| Split by same control | 1 |
| Fill page up and run over | 1 |
| Repeat picture if number of boxes > 6 | 1 |
| Break in forward sequence and use reverse sequence | 1 |

Table 2. The Important Rules Referred by The Participants

5. By row of switches or controls.

However, if these do not fit onto a page, one should go for a maximum of 3 pictures - 6 labels, 2 pictures - 7 labels, and then continue on next page, with the picture repeated and a note to specify that it is the "same procedure which is continuing."

## 3.3 The Procedure Splitting Algorithm

### 3.3.1 Derivation of the breaking rules

Before it is possible to decide how to build an algorithm incorporating these rules, still more needs to be learned about the identification process in the data base of the following elements:

a) difference between the labels (i.e., Act, Response and Note information boxes etc.),

b) different panels,

c) different systems and/or sub-systems,

d) the nature of the relationships between different panels,

e) the nature of the relationships between different systems and/or sub-systems.

That is, if it is feasible to build a data base along with the physical description of the pictures and labels (i.e., dimensions, relative coordinates of the internal points in the pictures ... etc.), the remaining question is how to supply the information (a, b, c, d and e) above.

The identification of the relationships between all the instruments panels (information (d)) on the overview (see Appendix A) and of all the systems, sub-systems and their relationships (information (c) and (e)) will necessarily require an extended period of investigation. This period will increase with the complexity of the equipment used in the JPAs and PTAs. Even for less complex equipment, the time needed to conduct the detailed identifications of system and sub-systems may remove all the benefit of the information, as a manual layout process could have been more efficient during that time. However, the identification of different label boxes and of the instrument panels are not time consuming tasks. They can be easily identified by the system user early in the preparation of the JPAs and PTAs materials.

Additional possibilities can be included to help the user to further humanize the splitting process. One such possibility is to include capability for the system to test for the "natural breaking points" which will be provided in the data at the option of the system user. For instance the user can be given choice to input any of the following as appropriate:

a) labels which must naturally be at the beginning of a new page,

b) labels which must naturally follow a previous indicator label,

c) labels which must naturally be at the end of a page.

This additional information can conveniently be supplied by the user in a single digit code to supplement the usual data. It is not mandatory and the system to be designed will work even if it is not specified by the user.

The analysis of the results from the questionnaire together with the above natural breaking points idea retain five different rules to break the procedure into sub-procedures so as to make each complete and fit in a page. These rules are the following:

1. the spatial feasibility rule of the page,
2. the maximum limits rule on the number of elements allows in the page,
3. the separation rule of the different instrument panels,
4. the separation rule of the different instruction labels,
5. the natural breaking points (if any) recommended by the user.

Rules 3, 4, and 5 are linked to the nature of the objects in the procedure being considered. They must be and are better controlled by the JPAs and PTAs designers. Rules 1 and 2 are closely linked to the dimensions of the objects involved and the space available in the page for the layout. It is correct to assume that, while the participants have not specifically attempted to layout every split produced by their other rules, they have had a mental consideration of the proportion of the surfaces shared in the layout space by the objects and by the margins. To account for this in the algorithm to split the procedure, a maximum percentage limit of the layout space can be established for the pictures and labels. This limit will serve as a breaking point for rule 1.

### 3.2.2 The Splitting Algorithm And Results

Appendix B described some related additional definitions of the materials in the JPAs and PTAs procedures. Specific assumptions on which the data base and the algorithm are built are also described in Appendix B. All of them are mainly of interest to detailed users of the system.

Using the assumptions in Appendix B, the algorithm initially selects the first picture (reads its information) to be part of a split. When a picture becomes part of a split, its labels starting from its first are each checked against the breaking rules and included in the split whenever no rule calls for the prevention of such inclusion. This addition of the labels related to the latest picture entered in the split continues until, (a) a rule is violated; (b) an interruption is found in the sequence of labels (see assumptions in Appendix B); (c) no more label remains for the picture under consideration. In case (a) and/or (b) the picture is candidate for duplication and is stored in a temporary data file. It is called for selection at the beginning of a new split (case (a) and not case (c)) or whenever its label is the next top label in the sequence (case (b)). In case (c) (and not case (a)), the next picture and its label(s) are considered candidates for the current split; prior to their selection several assumptions (see Appendix B) and all the breaking rules are checked to see if such an addition must be prevented; otherwise the picture is selected (its information read) to be part of the current split and the selection of its label(s) is done one at a time in the same manner as described above. More details of the algorithm and the organization of the computation are available in the Users Manual (Sylla and Babu (1982)).

Figure 16 shows the general steps of the algorithm in flowchart form. The flowchart shows the logical points where the rules are being checked. It also shows how and where the algorithm is attempting the duplication process and the process of minimizing the number of pages by entering more objects whenever possible in one page.

Except for rule 1 (the spatial feasibility rule of the page), the algorithm enforces every one of the breaking rules in the same manner the participants have done. This becomes possible as all the necessary

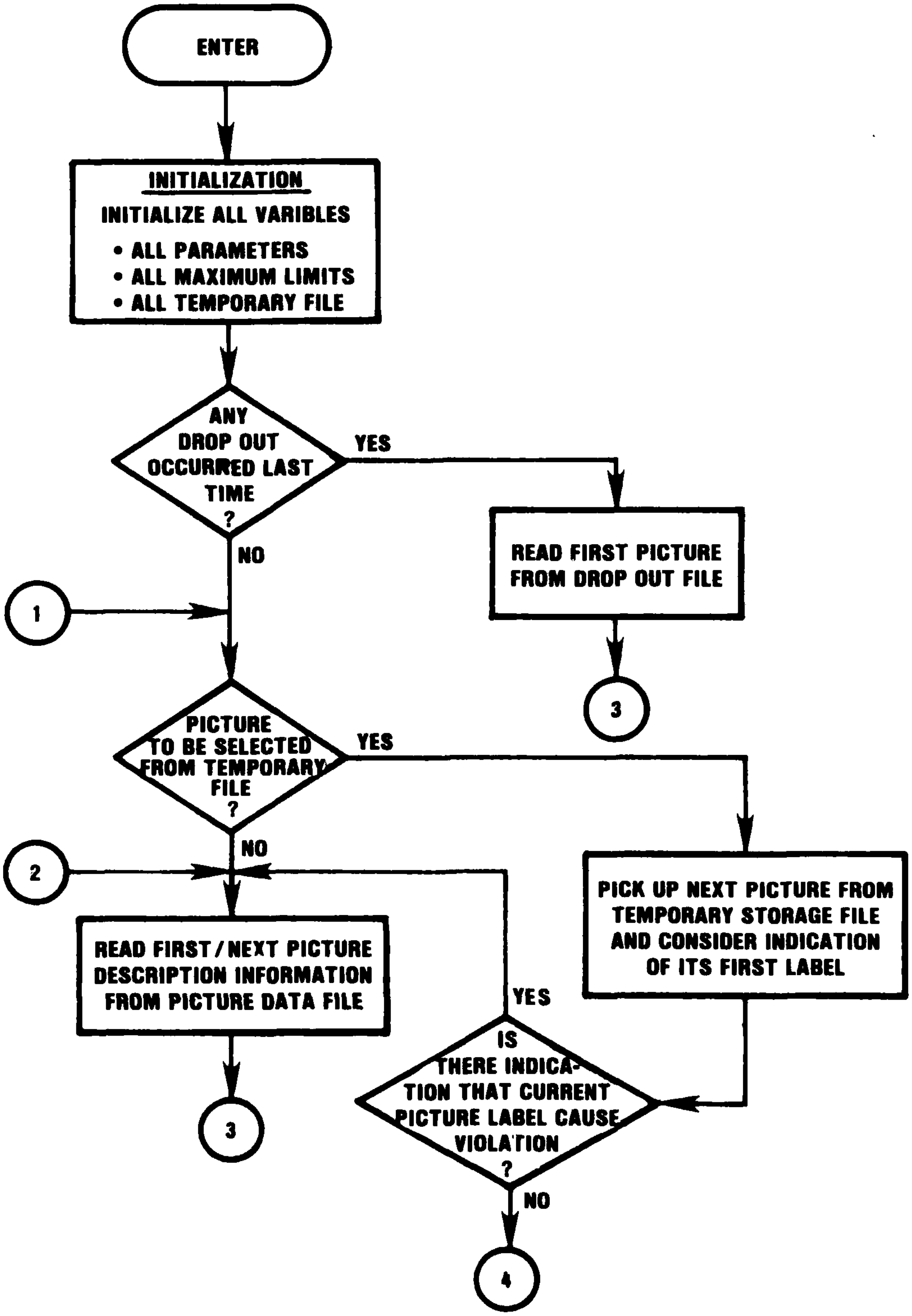

ENTER
INITIALIZATION
INITIALIZE ALL VARIBLES
• ALL PARAMETERS
• ALL MAXIMUM LIMITS
• ALL TEMPORARY FILE
ANY DROP OUT OCCURRED LAST TIME ?
YES
NO
READ FIRST PICTURE FROM DROP OUT FILE
1
3
PICTURE TO BE SELECTED FROM TEMPORARY FILE ?
YES
NO
2
PICK UP NEXT PICTURE FROM TEMPORARY STORAGE FILE AND CONSIDER INDICATION OF ITS FIRST LABEL
READ FIRST/NEXT PICTURE DESCRIPTION INFORMATION FROM PICTURE DATA FILE
YES
IS THERE INDICATION THAT CURRENT PICTURE LABEL CAUSE VIOLATION ?
3
NO
4

Figure 16a. The Subprocedure Splitting Algorithm

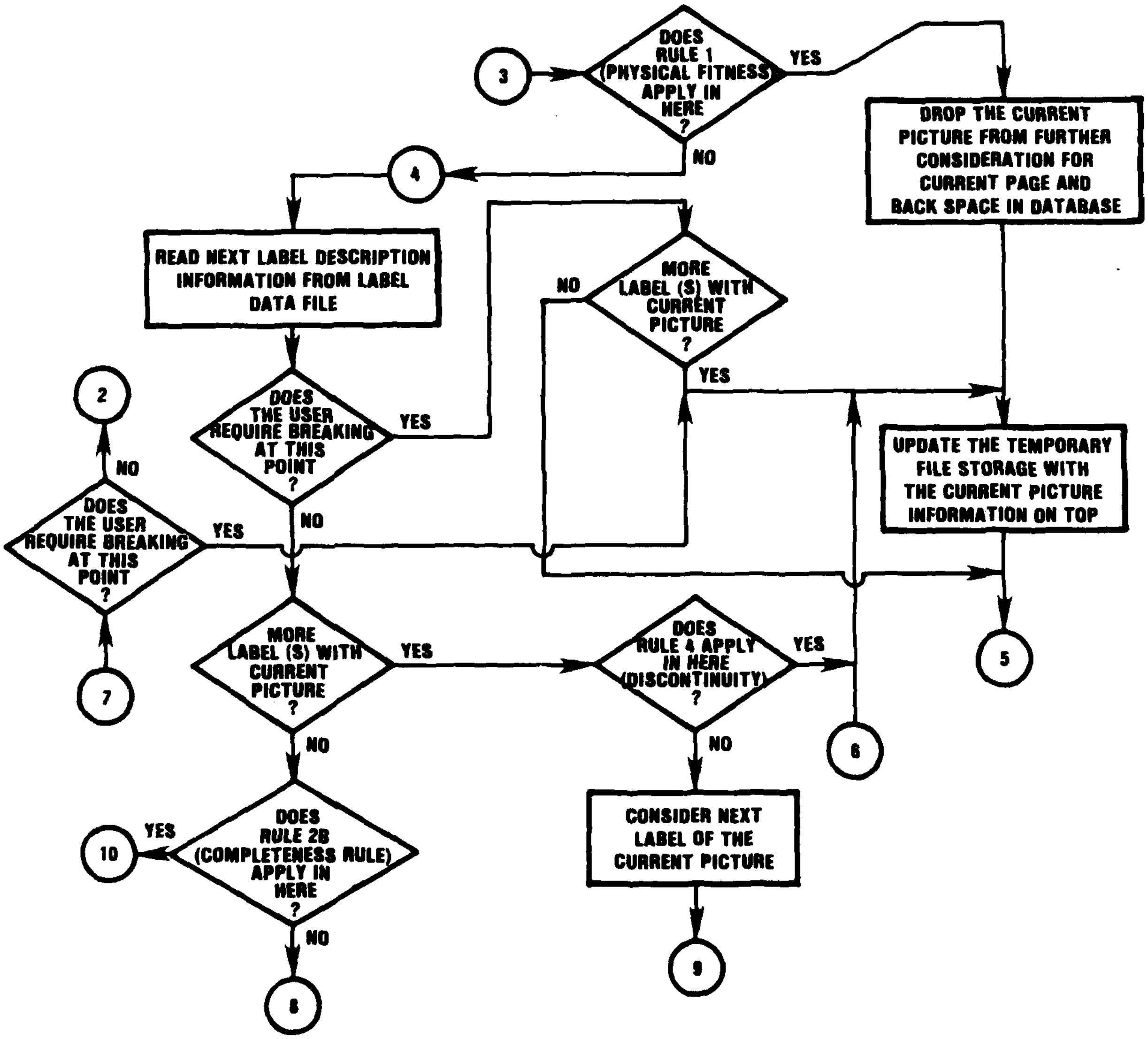
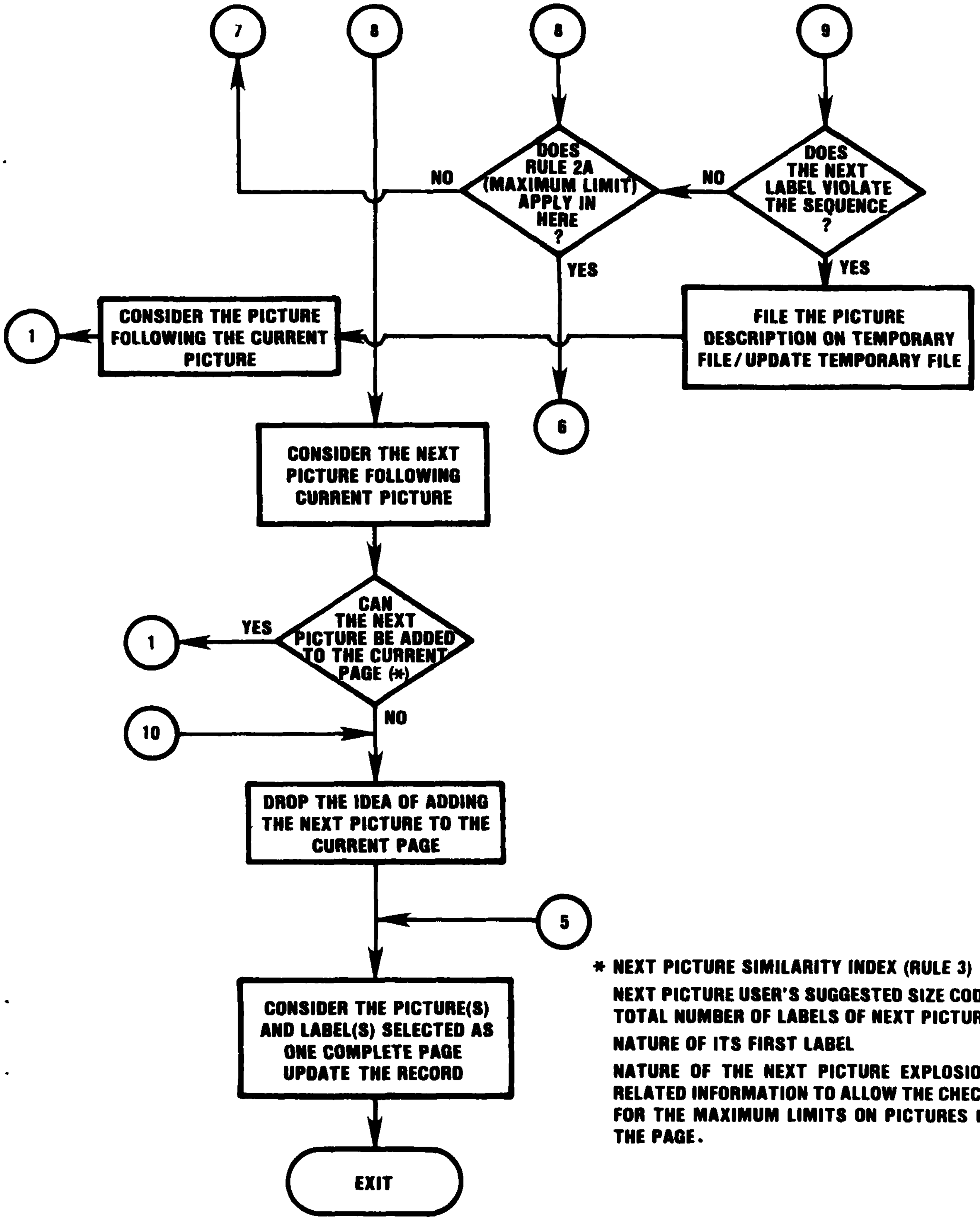

3
DOES RULE 1 (PHYSICAL FITNESS) APPLY IN HERE ?
YES
NO
DROP THE CURRENT PICTURE FROM FURTHER CONSIDERATION FOR CURRENT PAGE AND BACK SPACE IN DATABASE
4
READ NEXT LABEL DESCRIPTION INFORMATION FROM LABEL DATA FILE
MORE LABEL (S) WITH CURRENT PICTURE ?
NO
YES
2
NO
DOES THE USER REQUIRE BREAKING AT THIS POINT ?
YES
NO
DOES THE USER REQUIRE BREAKING AT THIS POINT ?
YES
UPDATE THE TEMPORARY FILE STORAGE WITH THE CURRENT PICTURE INFORMATION ON TOP
7
MORE LABEL (S) WITH CURRENT PICTURE ?
YES
DOES RULE 4 APPLY IN HERE (DISCONTINUITY) ?
YES
5
NO
6
NO
YES
10
DOES RULE 2B (COMPLETENESS RULE) APPLY IN HERE ?
NO
CONSIDER NEXT LABEL OF THE CURRENT PICTURE
9
8

Figure 16b. The Subprocedure Splitting Algorithm


7
8
8
9
DOES RULE 2A (MAXIMUM LIMIT) APPLY IN HERE ?
NO
YES
DOES THE NEXT LABEL VIOLATE THE SEQUENCE ?
NO
YES
CONSIDER THE PICTURE FOLLOWING THE CURRENT PICTURE
1
FILE THE PICTURE DESCRIPTION ON TEMPORARY FILE/UPDATE TEMPORARY FILE
6
CONSIDER THE NEXT PICTURE FOLLOWING CURRENT PICTURE
CAN THE NEXT PICTURE BE ADDED TO THE CURRENT PAGE (*)
YES
1
NO
10
DROP THE IDEA OF ADDING THE NEXT PICTURE TO THE CURRENT PAGE
5
CONSIDER THE PICTURE(S) AND LABEL(S) SELECTED AS ONE COMPLETE PAGE UPDATE THE RECORD
EXIT

* NEXT PICTURE SIMILARITY INDEX (RULE 3)

NEXT PICTURE USER'S SUGGESTED SIZE CODE
TOTAL NUMBER OF LABELS OF NEXT PICTURE

NATURE OF ITS FIRST LABEL

NATURE OF THE NEXT PICTURE EXPLOSION RELATED INFORMATION TO ALLOW THE CHECK FOR THE MAXIMUM LIMITS ON PICTURES IN THE PAGE.

Figure 16c. The Subprocedure Splitting Algorithm

instructions can be easily supplied to the computer. While the participants could and have not used an exact calculation, but rather "mental limits" for the proportions of the space in the page to allocate for the pictures and labels and for the margins (free white space in the page), the algorithm can use an exact calculation base on any predefined limits on these proportions. To do so effectively, the algorithm uses the following two different spatial feasibility tests:

(1) A preventive test is conducted as soon as the information concerning the physical dimensions of the picture of concern and its labels become available. For this test, the total area requirement of the elements already in the split and of the new elements for addition is computed and compared against the allocated proportion for the picture in the page (say 100%, 90%, 80% or 70% ... etc. for the pictures and labels space in the page, and therefore 0%, 10%, 20%, 30% ... etc. respectively for the margins).

(2) A more exhaustive test to verify if the pictures in the split will fit in the allocated proportion according to at least one of the predefined preference orders. These orders are established to enhance the good layout and readability. The details about these orders are discussed in the next chapters.

The tests are done in the above order as the first test is easier and cheaper in terms of computer time. They both are good safeguards to insure compliance with rule 1 at the splitting stage and to increase the probability of acceptance of the resulting split at the validation stage.

To make the computer enforce rule 1 so as to cause splits identical to the splits generated by the participants, it is necessary to set the limit to be used by the computer approximately the "mental limits" of all the participants. A possible experiment to find such a limit is to run the algorithm using different proportions for the allocation of the spaces in the page. For instance it is possible to use the following limits (i.e. 100%, 90%, 80%, 70%, 60% and 50%) for the proportion of the page to be allocated for the pictures and labels in the split. The use of these limits generate 6 computer runs (6 computer breaking results) for each of the three procedures. Table 3 shows the results of the average number of splits of each procedure provoked by the participants and by the computer using the different limits. Table 4 shows the same results in terms of the composition of the splits. The columns in this table are the same as in Table 1 seen previously, and the average participants are the average of the columns in that table. The two tables indicate that the 50% limit rule deviates at all time from the remaining limits used. The 100%, 90%, and 80% limit rules provoke the same number of splits when applied to each procedure, and the total number of pages under each for the 112 task steps is 26 pages which is slightly closer to the average of 28 obtained by participants than the 70% or 60% limit rules. The split composition results in Table 3 shows the 70% limit rule to be the closest to the participants in terms of the content of the elements in each split. Figure 17, shows the graph of the data in this table, to help better visualize this observation.

Figures 18, 19 and 20 show the histograms of the frequencies of the splitting points of the participants at each task step for each procedure.

| Splitting Results | Procedure 1 (13 task steps) | Procedure 2 (21 task steps) | Procedure 3 (78 task steps) | Total # of pages (row) |
|---|---|---|---|---|
| Ave.-participants | 3 | 5.8 | 19.2 | 28 |
| Algo 100% | 3 | 7 | 16 | 26 |
| Algo 90% | 3 | 7 | 16 | 26 |
| Algo 80% | 3 | 7 | 16 | 26 |
| Algo 70% | 3 | 7 | 21 | 31 |
| Algo 60% | 3 | 7 | 23 | 33 |
| Algo 50% | 4 | 10 | 26 | 40 |

Table 5. Resultant Numbers of Split For Each Procedure By The Participants and The Algorithm Using Different Limit Rules

| Columns / Splitting Results | Frequency |  |  |  |  |  |  |  |  |  |  |  | Total = of pages (row) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |  |
| Ave.-participants | 11 | 8.28 | 2 | 3.9 | 1.64 | 0.14 | 1.35 | 0.42 | 0.42 | 0.071 | 0.071 | 0.214 | 28 |
| Algo 100 | 5 | 9 | 2 | 5 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 26 |
| Algo 90 | 5 | 9 | 2 | 5 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 26 |
| Algo 80 | 5 | 9 | 2 | 5 | 1 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 26 |
| Algo 70 | 11 | 13 | 2 | 4 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 32 |
| Algo 60 | 16 | 15 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34 |
| Algo 50 | 28 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |

Table 4. Composition of Resultant Splits in Terms of Number of Elements in Columns Specified in Table 1.

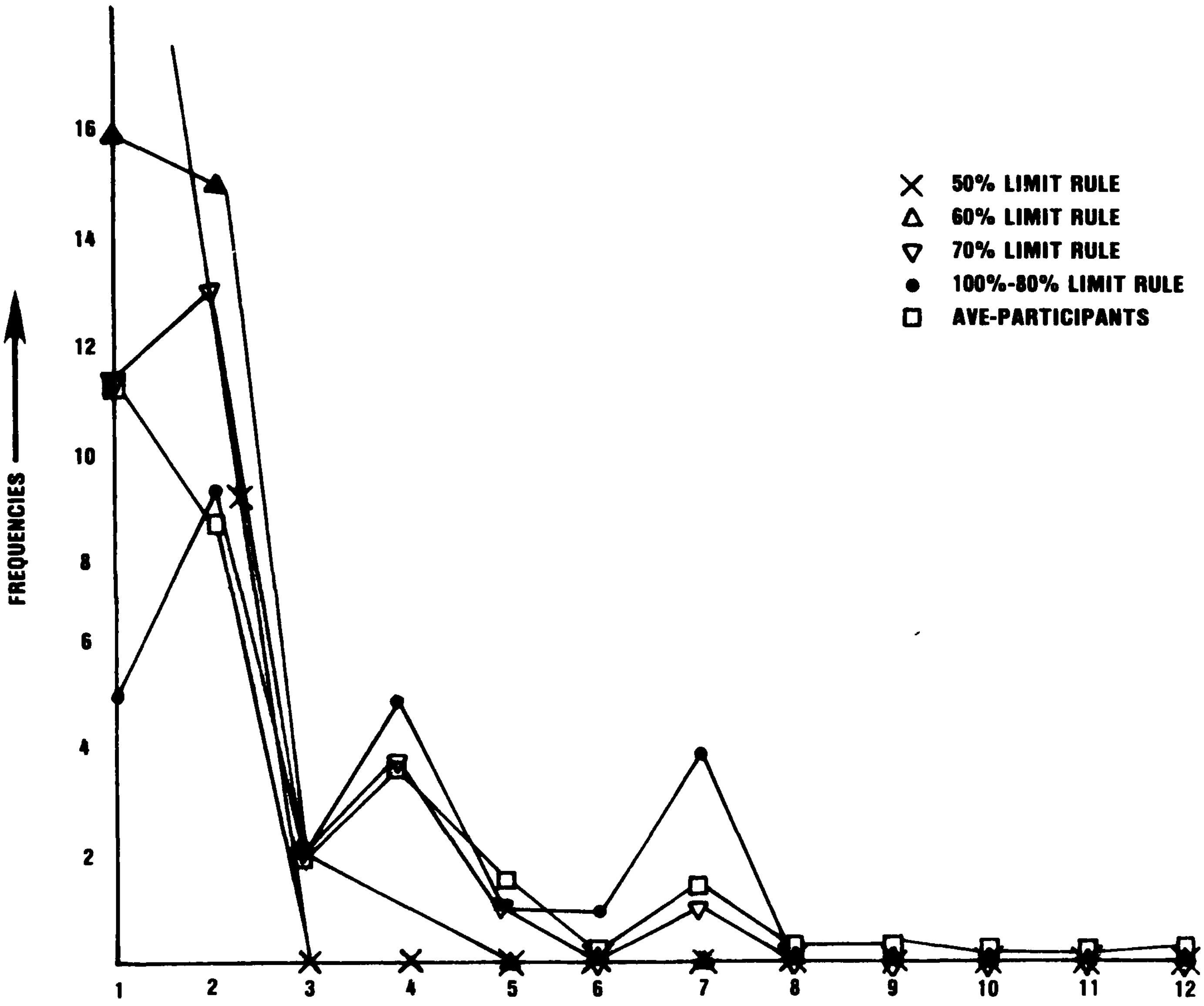


Figure 17. Graphs of the Composition in The Splits in Table 3.
(see columns descriptions with Table 1)

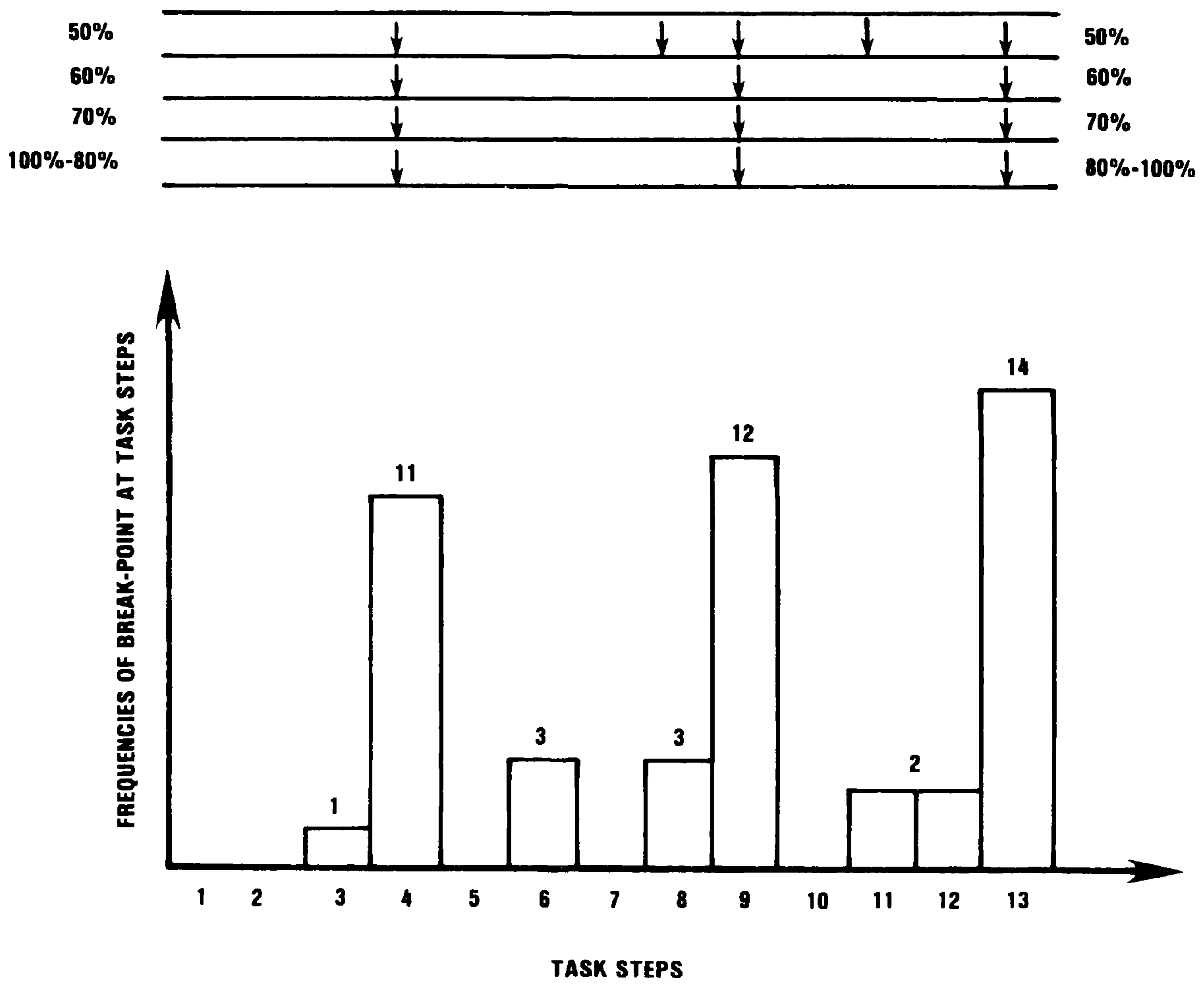


Figure 18. Histogram of The Splitting Points (Procedure 1)

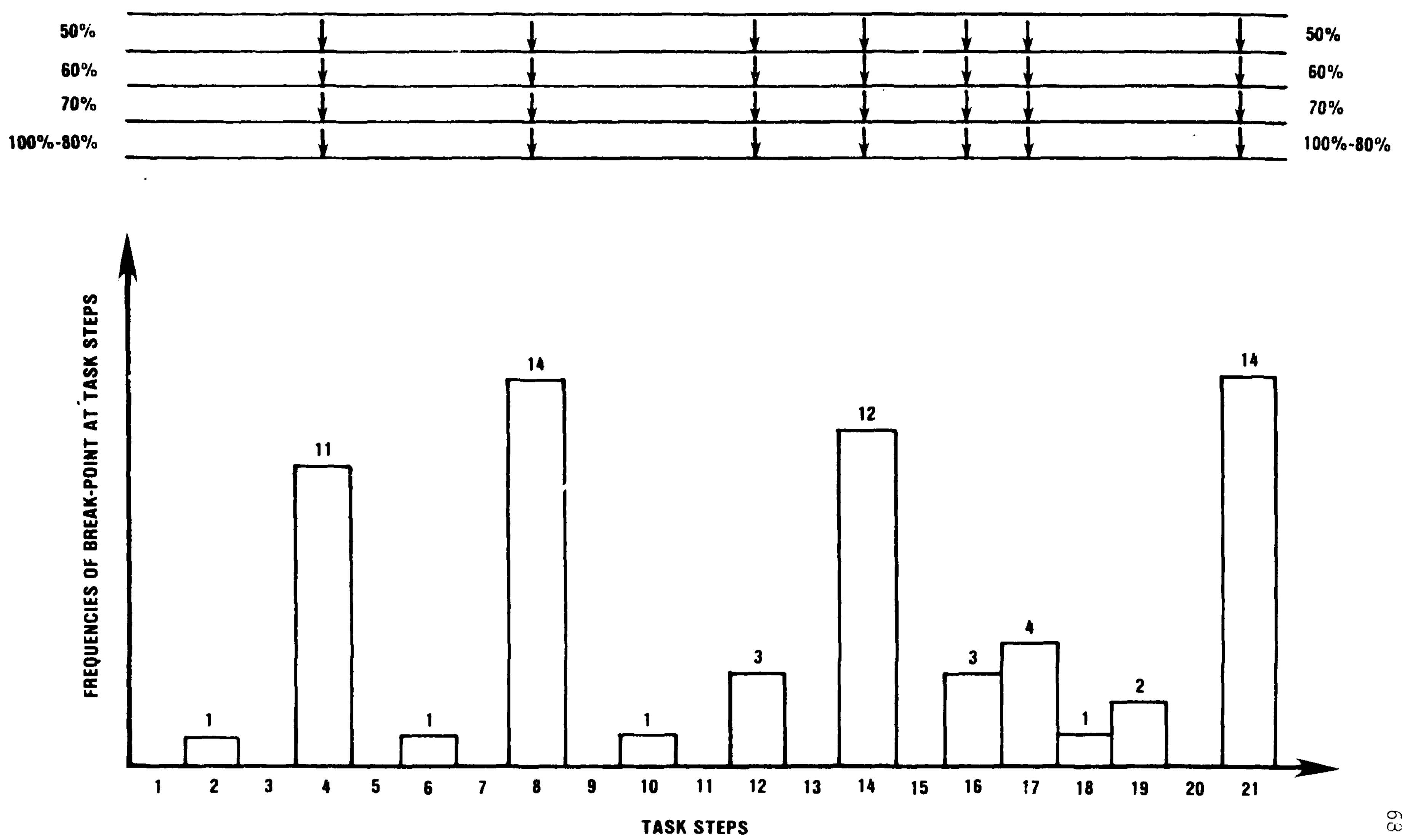


Figure 19. Histogram of The Splitting Points (Procedure 2)

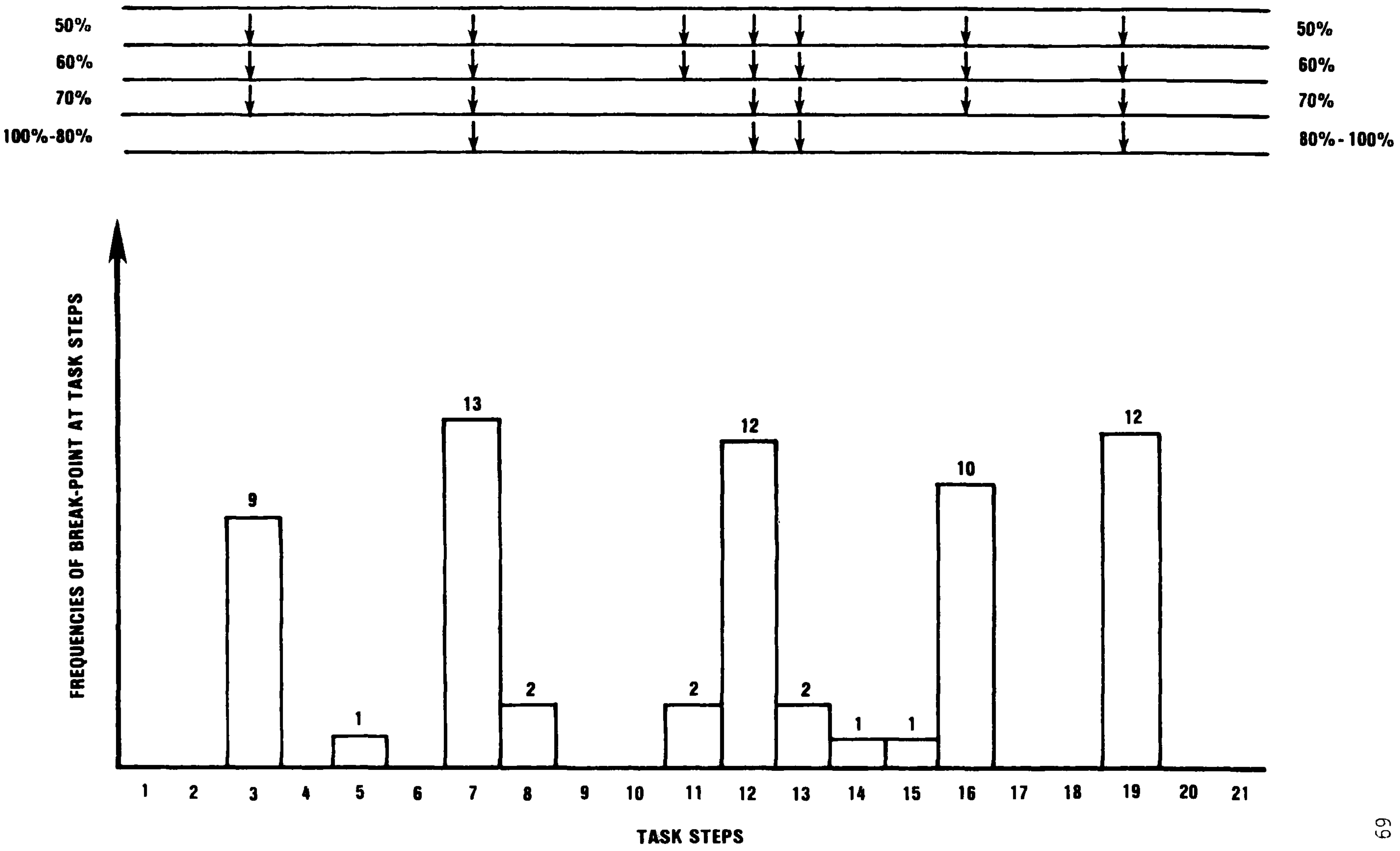


Figure 20a. Histogram of the splitting-points (Procedure 3)

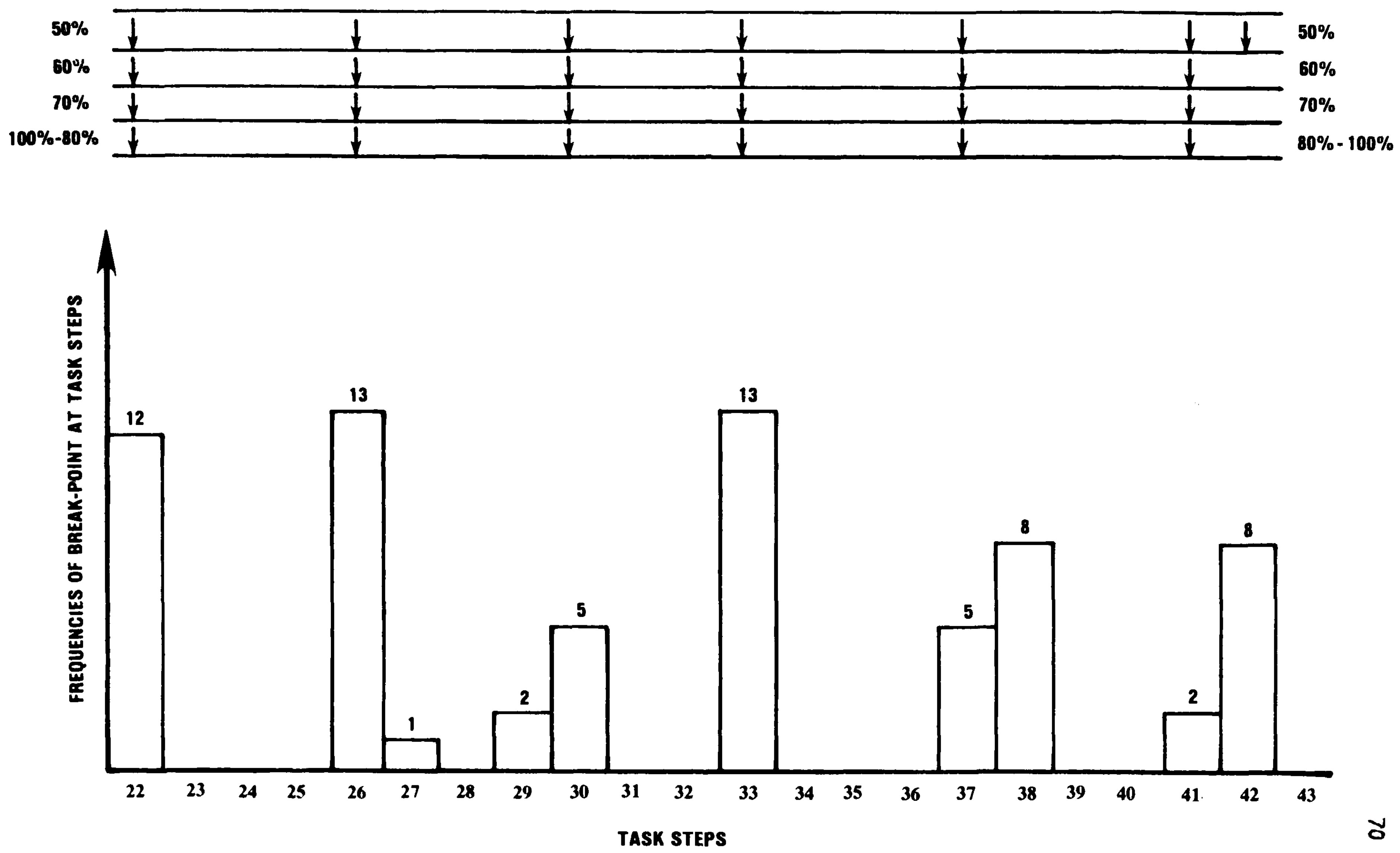
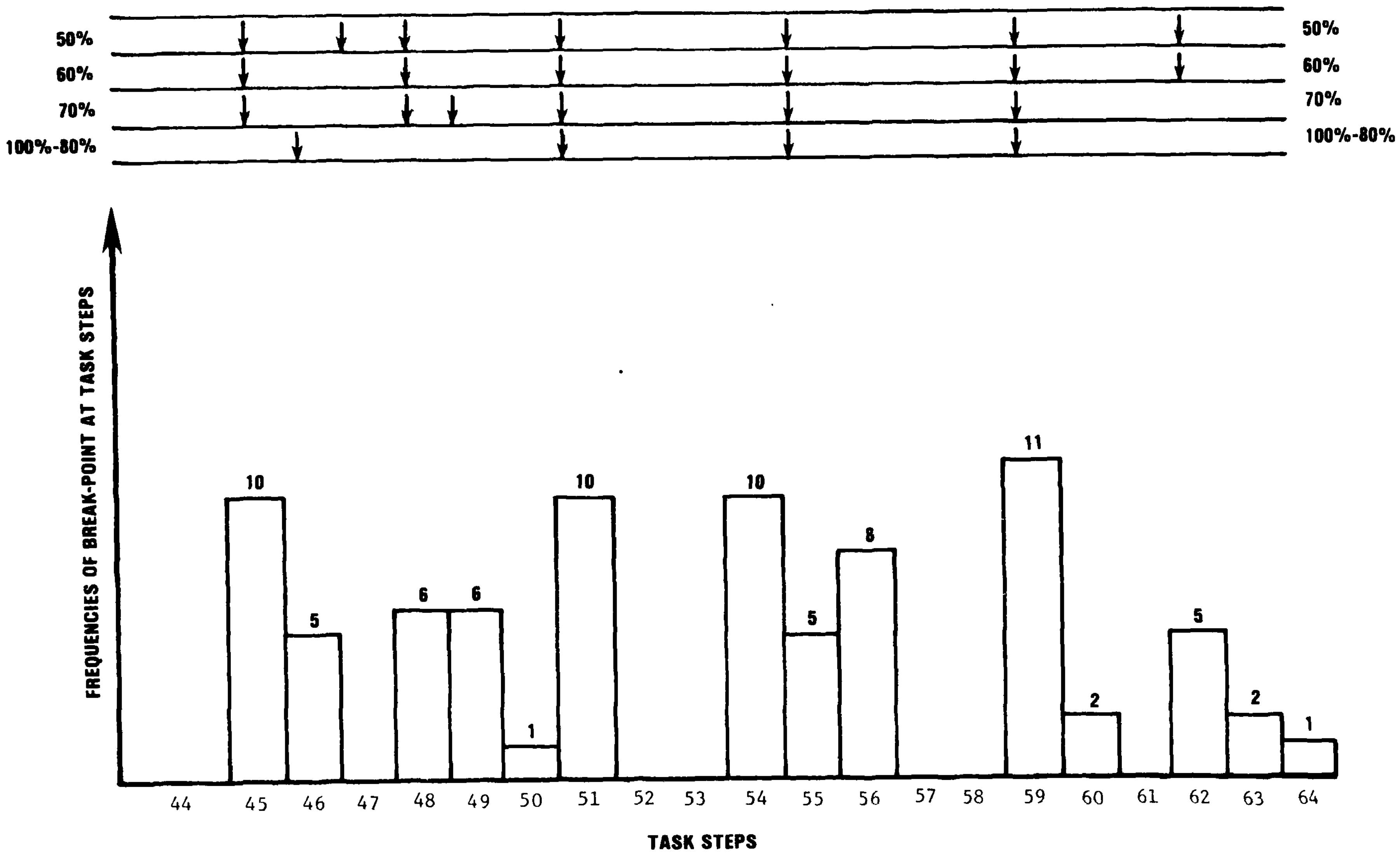


Figure 20b. Histogram of the splitting-points (Procedure 3)



Fiqure 20c. Histogram of the splitting-points (Procedure 3)

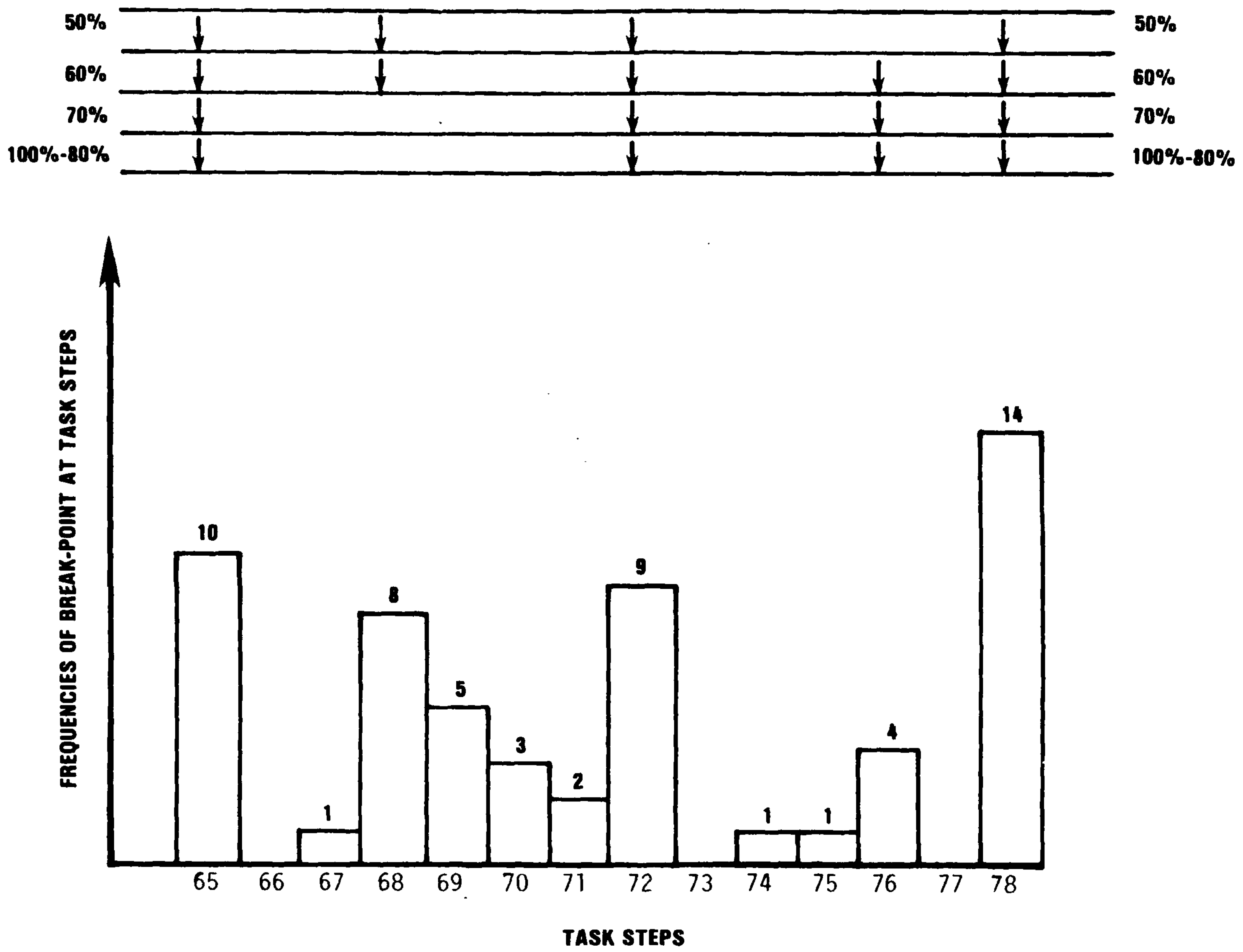


Figure 20d. Histogram of the splitting-points (Procedure 3)

Arrows are used in the same figures to show the splitting points of the computer algorithm with each limit rule. It can be seen in the results of Figures 18 and 19, that a general strong agreement exists not only between all the participants splitting points, but also between the participants and the computer algorithm splitting points. This is certainly due to the fact that all the splitting points (except for the case of the 50% limit rule) in the corresponding two procedures are caused by the other splitting rules (i.e., 2, 3, 4, and 5) and not by the spatial feasibility rule (i.e., rule 1). However, the results in the third procedure (Figure 20) show some disagreement at all the levels. There are less peaks between the participants starting at about task step 37. The computer algorithm results with the 70% limit rule seems to be going along well with most of the significant peaks. This suggests once more that the 70% limit rule is the most appropriate choice to use in the computer algorithm in order to make the computer algorithm behave like a "knowledgeable person". This conclusion is based on the same data of the questionnaires. The computer program is deterministic in contrast to the sample of "knowledgeable people", hence we would expect the algorithm to show greater consistency on long procedures than a diverse set of human beings.

Another important consideration is the relationship between the limit rules and the total number of pages which can result from the use of such rules. The higher the percentage limit (e.g. 100%) the smaller is the total number of splits and consequently smaller the number of layout pages. This small number of layout pages will result in a significant reduction of the manual pages if many JPA and PTA procedural steps must be laid out. But with such a high limit the number of elements tend to be greater in each split. Therefore successful validation of the splits become less likely without some reconstructions and additional computer time. The readability problem also exists whenever too many elements are present in the splits. The problem of how to set the limit to obtain the optimum number of elements in the splits for improved readability can only be resolved through experimentation beyond the scope of the present research.

## 3.4 Summary

This chapter has presented the two major problems related to the layout of a procedure. A simplified model to deal with this general layout problem was introduced showing how solution mechanisms of the two problems interact. One of the two problems, the splitting of the lengthy procedure into sub-procedures so as to fit each into a page, was discussed in detail. It was shown that the problem lies in a delicate area involving man-machine interfacing. A questionnaire was designed to help investigate the factors involved. It was shown how the responses of the questionnaire were analyzed and used to build a splitting algorithm. Different limit rules were used to make the algorithm enforce the spatial feasibility rule, and the results were compared to the questionnaires responses. The 70% limit rule was shown to generate splits which were similar to the splits generated by the human. The discussion of the results was extended to other aspects of the splitting problem related to the number of elements in the splits. The next chapters will examine the layout problem.

# CHAPTER IV

# PAGE LAYOUT

Whether a procedure is short or lengthy the layout of the task steps (in label boxes) and accompanying illustrations (in rectangular form) must be done to generate suitable arrangement in format ready for mass-production by the automatic set-up publishing system. The detailed definitions of the objects involved and the general description of the arrangement problem requirement were given in Chapter I. Several problems are related to this layout (validation) phase of the overall solution and any attempt to handle all of them at once is almost certain to fail. That is, development of a solution procedure starting with the solution of simplest of the problems (simple page layout) and augmenting progressively the complexity of this solution to handle the difficult aspects of complex problems (complex page layouts). Following this idea the layout of the simple page which can contain up to two pictures (where one is always assumed to be the overview picture) will be first investigated, a model formulated and a solution method developed. Next this model will be generalized to include all the added complexity of the page containing more than two pictures, and the required modification of the solution method for the simple page will be presented.

## 4.1 Simple Page Layout Problem

The simple page layout problem fits all the description of the layout problem detailed previously in Section 1.3 and all the general objectives and constraints whereby described are same. The only difference with this problem is that the number of pictures in the page is not to exceed two.

## 4.2 Assumptions

To permit the use of the mathematical optimization techniques or any other systematic problem solving method using the computer, certain assumptions must be made about the problem with respect to the limitation of these methods. The assumptions made for the model of the simple page layout are:

(1) The maximum number of objects considered in the page are not to exceed the maximum suggested by the splitting procedure examined in the previous chapter. For the simple page layout these maximum are set at 2 pictures (including one overview picture) and 7 labels.

(2) The arrangement between the labels when they are in the layout is assumed to be clockwise starting at any time on the clock anywhere on the page (although any other suitable arrangement than clockwise can be used). The starting label is always linked to internal point number 1 and will be recognized as such. In the final solution this label will be made recognizable by occupying a certain prespecified position of the clock or by being made darker or in a color different from the color of the other labels.

(3) The sizes of the objects are conveniently small to allow for several arrangements of the objects in a page.

(4) The label boxes are approximately of the same instructional length allowing the label boxes to be interchangeable in the clockwise arrangement.

(5) Only one arrow will be linking a label box to the internal point in the close-up or enlarged view picture. That is, if many devices (whose locations are illustrated by the internal points) in this picture are to be linked to one label slot, the center of gravity of these devices will be considered to represent them all, and only one arrow will be designed to link this point to the corresponding label box.

## 4.3 Model of the Simple Page Layout

### Page Composition Analysis

The layout design of the pictures and label boxes with linking arrows in a typical format for procedure (recall the figures in Section 1.3), clearly requires several components if a systematic solution procedure must be used with computer routines. A typical way to handle this design problem is to consider it as having two main components. That is regardless of the number of pictures and label boxes split for inclusion in one page by the splitting process described in Section 3.2.3, it is feasible to investigate the layout problem of every page in two main components which are:

(1) The placement component or layout of the pictures in the page. Enough space is required around the pictures having internal points that are to be linked to label boxes with arrows.

(2) The placement components of the labels or arrangement assignment of them. Preferably the labels should be closer to internal points to be linked with arrows.

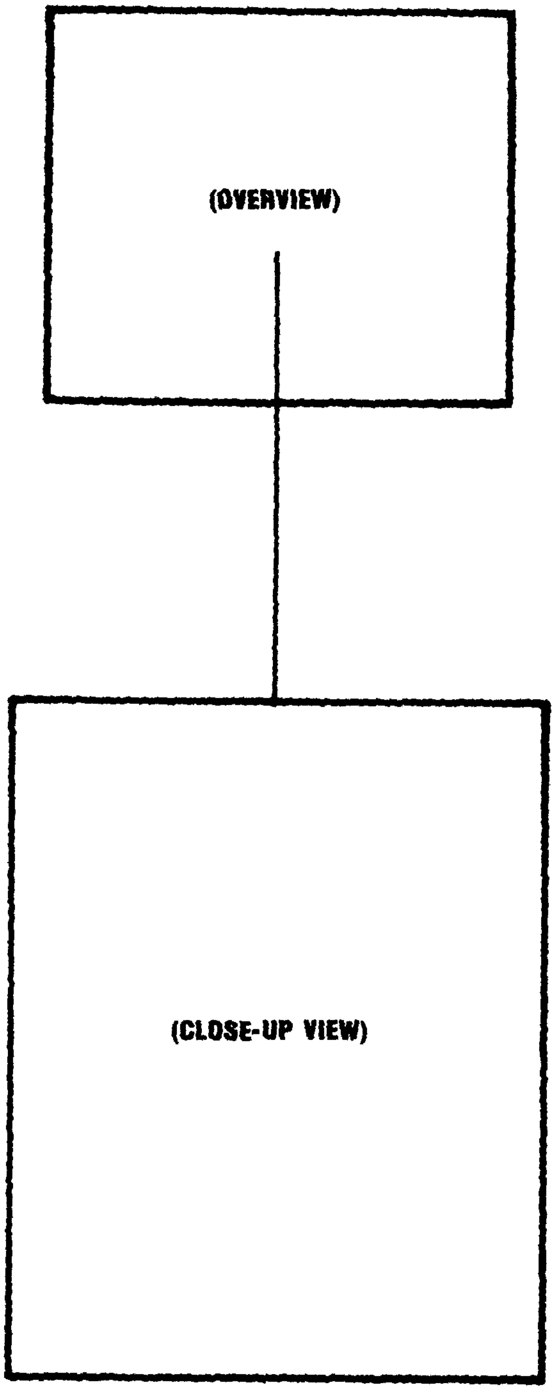


Figure 21. Illustration of a Layout Page with Overview and Single Picture

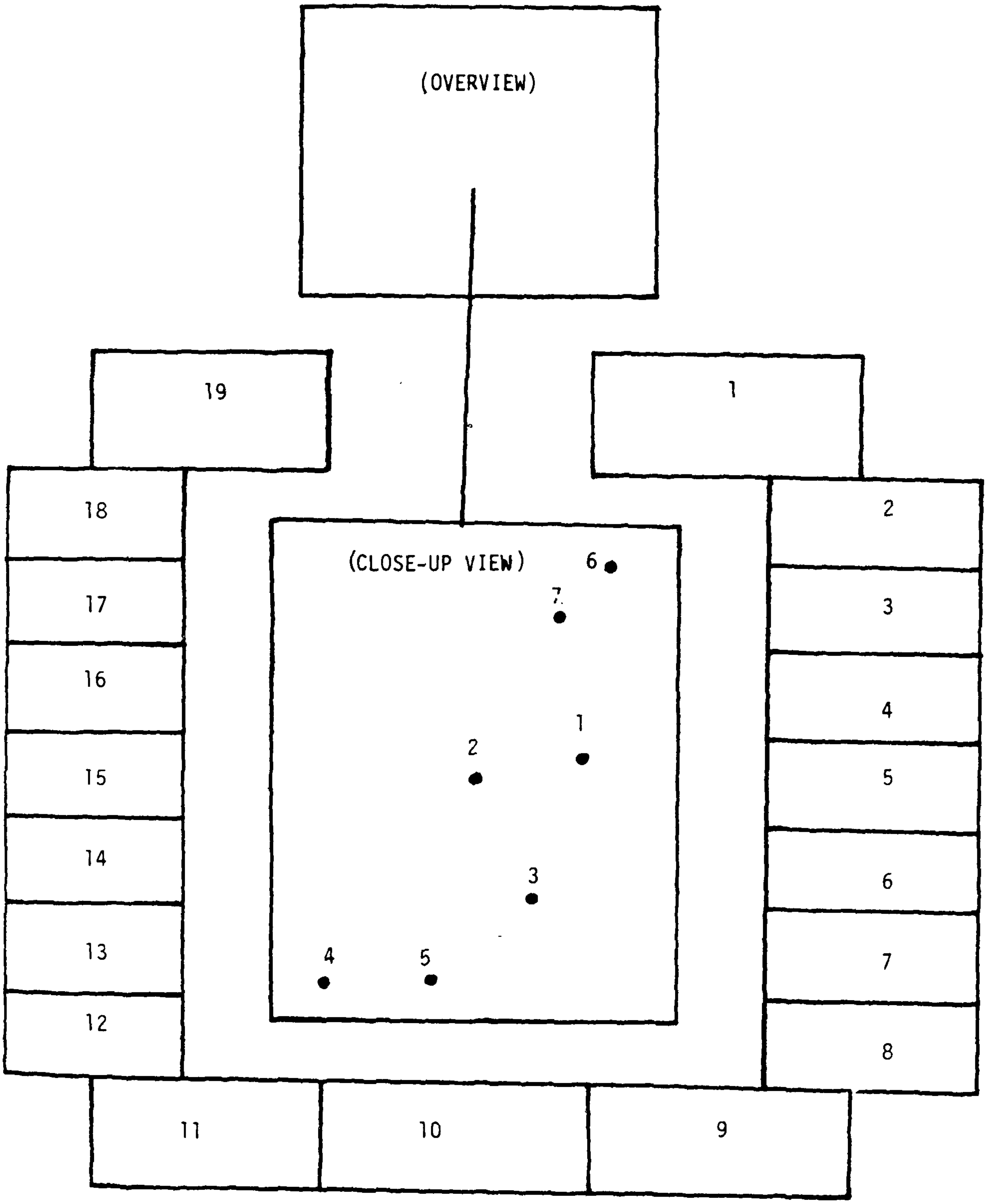


Figure 22. Illustration of Potential Label Slots around the Close-up View Picture

Both of these components must be structured subject to all the requirements specified in the overall problem description in Section 1.3.1. The placement component or layout of the pictures in the page is investigated in detail in a previous work by Babu and Sylla (1981); a modification of the solution algorithm proposed in that work will be used to handle the placement component of the pictures. A complete detail of the development of placement of the pictures will be shown in a later chapter dealing with the solution procedure of the complex page layout problem.

## The Placement Component of The Labels

When a simple page containing an overview picture and a close-up view picture which includes N internal points is to be laid out, one method is to place the close-up view picture below the overview picture as in Figure 21; the problem is then to arrange the labeling statements in boxes around the picture with linking arrows to those internal points to which the statements correspond. The procedure to handle this problem is given below (see Figure 22):

1) First draw M potential label slots $(M \geq N$, where $N$ is the number of internal points in the close-up view picture) in the remaining space around the picture. If $(M - N) > 0$, it can be assumed that $(M - N)$ redundant internal points exist in the central picture.

2) The problem is then one of choosing among the M label slots, N label slots to be linked to the N internal points in the picture.

This problem, which will be referred to as the Assignment Arrangement Problem (AAP), can be stated as follows:

A. Minimize:

1. The sum of the lengths of the arrows between each internal point $i$ $(i=1,\ldots,N)$ and its assigned label slot $j$ $(j=1,\ldots,M)$;
2. The sum of the lengths of the arrows within the picture to link internal point $i(i=1,\ldots,N)$ to its assigned label slot $j(j=1,\ldots,M)$ . (See Figure 23);
3. The number of intersections between the arrows.

B. In such a way that:

1. Each internal point $i$ is being assigned (linked) to exactly one label slot $j$ (i.e., exactly one arrow begins from each label slot $j$).
2. Exactly one label slot $j$ is assigned to each internal point $i$ (i.e., exactly one arrow begins from each label slot, $j$ , to end at each internal point, $i$, in the picture).
3. A pre-specified arrangement exists among the assigned label slots.

This (AAP) can be stated mathematically as follows:

$$\underline{\text{Minimize}} \quad f(x) = \sum_i \sum_j \sum_k \sum_\ell (C_{ijkl,a})\, X_{ij}\, X_{k\ell}$$

$$\underline{\text{Subject to}} \quad 1) \quad \sum_i X_{ij} = 1 \qquad \text{for all } j$$

$$2) \quad \sum_j X_{ij} = 1 \qquad \text{for all } i$$

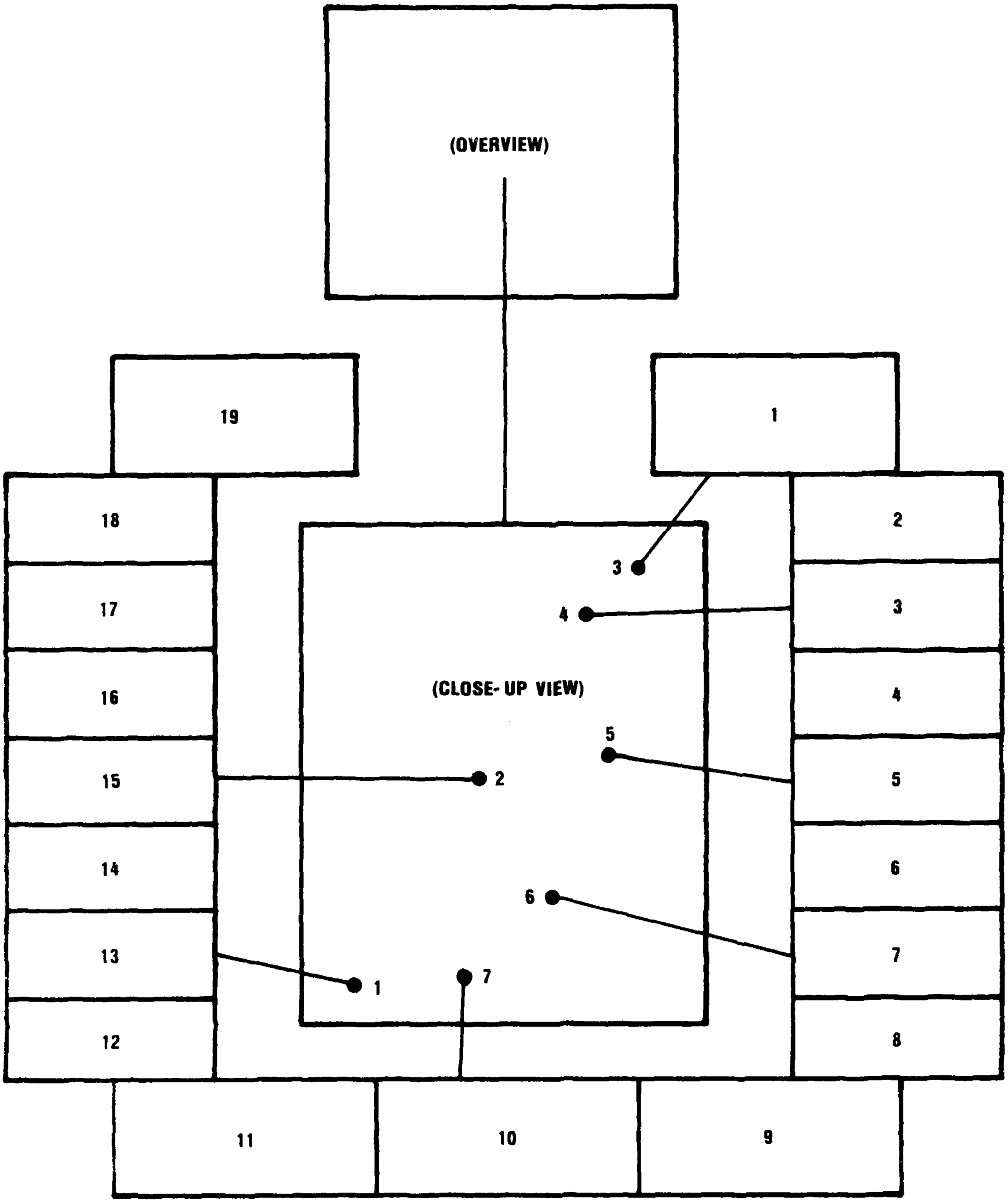


Figure 23. Illustration of an Assignment of The Internal Points to The Label Slots. Notice that this Assignment is Clockwise Starting at Approximately 8 o'clock.

AD-A139 347 COMPUTER AIDED LAYOUT OF PROCEDURE INFORMATION FOR 2/3
TRAINING AND JOB AIDIN..(U) STATE UNIV OF NEW YORK AT
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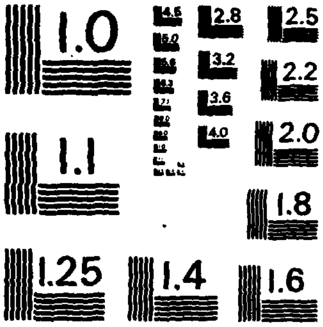
UNCLASSIFIED DEC 83 TAEG-TN-11-83 N61339-81-C-0091 F/G 5/9 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

3) $X_{ij} = \begin{cases} 1, & \text{if internal point } i \text{ is assigned to label slot } j \text{ (i.e., an arrow links label slot } j \text{ to internal point } i\text{)} \\ 0 & \text{otherwise} \end{cases}$

where $(C_{ijk\ell,a})$ specifies the cost due to interaction of assignments $(ij)$ and $(k\ell)$ including all penalty costs, if any, due to violation by the two assignments in the overall clockwise arrangement between the label slots.

This formulation is a modified quadratic assignment problem (MQAP) as the assignment is subject to the user's pre-specified arrangement of the labels. Given an assignment of internal points to label slots, it is instructive to let $a(i)$ denote the number of the label slot to which internal point $i$ is assigned and to let $a$ be the assignment vector

$$a = (a(1),a(2),\ldots,a(m)). \tag{1}$$

Note that the ith component of the assignment vector in (1) is the number of the label slot to which internal point $i$ has been assigned.

As an illustration of the use of the assignment vector, suppose that the internal points of the picture in Figure 21 are assigned to the label slots in that same figure according to the assignment vector.

$$a = (13, 15, 1, 3, 5, 7, 10,\ldots) \tag{2}$$

then the arrows will be linking the label to the internal points as shown in Figure 23. Thus, for this assignment $X_{1\ 13}$, $X_{2\ 15}$, $X_{3\ 1}$, $X_{4\ 3}$, $X_{5\ 5}$, $X_{6\ 7}$ and $X_{7\ 10}$ are equal to one and all other $X_{ik}$ are zero.

Given an assignment of the internal points to label slots, the next step is to evaluate the total cost for the assignment. The total cost for the assignment is composed of the following (See Appendix C1 for notation).

a) the cost of violation of (deviation from) specifications of arrangement between the labels (i.e., vertical order, horizontal order, clockwise order, etc.).

Objective 1: $$c(a) \qquad (3)$$

b) the total cost of all intersections between the arrows in the assignment.

Objective 2: $$\sum_{ij} W_{ij} I(a(i),a(j)) \qquad (4)$$

c) the total cost of the sum of the lengths within the picture of all arrows in the assignment.

Objective 3: $$\sum_{i} \overline{d}(a(i)) \qquad (5)$$

d) the total cost of the sum of the lengths of all the arrows in the assignment.

Objective 4: $$\sum_{i} d(a(i)) \qquad (6)$$

The "costs" appearing in these four objectives correspond to the respective reductions in the "readability" of the resulting layout. The readability is assumed to be enhanced as each one of these four (conflicting) objectives is reduced. Hence it is ideal to minimize all these objectives for a particular layout. It may not be possible in reality to do so as the objectives are conflicting, i.e., while improving on one objective, another objective might get hurt.

The branch of mathematical programming (optimization) dealing with this type of problem with several objectives is known as multicriteria (multi-objective) programming. Here we consider three of the major approaches generally used to tackle such a problem. Selection of the appropriate method is done by interacting with the program user or the decision maker (abbreviated as DM). This interaction may take place either before or during the solution procedure. The three methods are (a) the weighted sum method, (b) the pre-emptive goals method, (c) the pre-emptive priorities method. The methods are discussed below.

a) Weighted Sum Method

If all the (four) objectives are of "comparable importance" to the DM, he will be required to assign appropriate "weights" to quantify the relative importance of each objective in the page layout. The weighted sum of all the (four) objectives is taken as a "single objective" and a layout is chosen which minimizes this "single objective expression".

For instance, if A,B,C,D are the "weights" assigned to the four objectives respectively, the single objective to be considered for minimization is the following:

$$T(a) = A \cdot C(a) + B \cdot \sum_{ij} W_{ij} I(a(i),a(j)) + C \cdot \sum \bar{d}(a(i))$$

$$+ D \cdot \sum_{i} d(a(i)) \qquad (7)$$

$$\text{or}\quad T(a) = A \;\text{(objective 1)} + B \;\text{(objective 2)} + C \;\text{(objective 3)} + D\;\text{(objective 4)}\;. \tag{8}$$

Functional forms other than (8) have been used in the multicriteria literature (see Villarreal, 1979 and Zionts, 1977), and the terms A, B, C, D have often been called multipliers. Also the assignment of the A, B, C, D may be done only once by the decision maker at the beginning of the solution procedure or continuously throughout in an interactive manner. While the methods which require a unique intervention of the DM may seem more practical, the solution depends also on the DM's experience and predictive ability. For this reason interactive solution procedure has received more attention and currently many methods using this procedure for solving multicriteria programming problems have been developed. Some of these methods are due to Geoffrion, et. al. (1972), Dyer (1972), Chankong and Haimes (1977), Zionts (1977), Zionts and Wallenius (1976), Villarreal and Karwan (1981), and many others.

The variable $(x_{ij}, x_{kl})$ in the (AAP) are all required to be integer and the interaction cost involves a quadratic term, therefore the problem as such, is a multicriteria nonlinear integer programming problem. In addition the problem at hand is very ill-structured. No methods are available to date to solve implicitly such a multicriteria nonlinear integer programming problem. Even if such an implicit solution were available, the conversion of the objective terms in expressions (7) into the same unit of measurement so as to give a basis for the DM to provide his estimate for the weights or multipliers coefficients A, B, C, D, remain to be derived. As it can be seen the nature of the objectives hardly allow such conversion scheme. Given the uncommon aspect of the objectives in the (AAP) at hand, the present study concludes that the conversion of the terms 3, 4, 5 and 6 into a common unit of measurement may only be feasible when considerable experience of the layout of JPAs and PTAs is gained. Clearly until that is done the (AAP) cannot be solved using any multicriteria technique based on the weighted sum or related methods.

b) Pre-emptive Goals Method

An approach to circumvent the difficulty of the weighted sum method has often been the pre-emptive goals method (e.g. Ijiri, 1965; Lee, 1972) also called the Lexicographic goal programming (see Ignizio, 1979). In this method, the DM is not asked to provide weights, but instead, he is required to rank the alternative objectives involved (i.e., 1, 2, 3, 4) and to specify his aspiration level for each of them. That is, the DM will be asked (before the technical methodology is designed to solve the problem) to rank the objectives 1, 2, 3, 4 in order of their importance to him in a final layout page and, the aspiration level he wishes to see each objective attair in this layout. To illustrate how goal programming is used to tackle problems like the (AAP) let us define:

$f_i(\overline{x})$ = the mathematical representation of objective i as a function of decision variables $\overline{x} = x_{11}, x_{12} \ldots x_{MM}$, i=1,2,3,4. ($f_i(\overline{x})$ here is a complicated nonlinear function)

$b_i$ = the aspiration level associated with goal $i$, $i=1,2,3,4$ (i.e., maximum number of violations in the prespecified arrangement, maximum number of arrow crossings etc.)

It is assumed that the DM wishes to have a layout page in which $f_i(\bar{x})$ equals or is very close to the aspiration level $b_i$ . In goal programming the next step is generally to let $n_i$ be the negative (under) deviation associated with goal $i$ and $p_i$ be the positive (over) deviation of goal $i$ . The DM is then asked to provide a ranking of the four objectives, and the minimum to this ranking is then found and considered optimal.

To illustrate the above steps of this method application to the (AAP) let us assume that the DM has the rank of the four objectives 1, 2, 3 and 4 as represented by the rank of the numbers. The goal programming method generally changes these objectives to goals via the determination of corresponding aspiration levels as follows:

$$G_1: \quad f_1(\bar{x}) + n_1 - p_1 = b_1$$

$$G_2: \quad f_2(\bar{x}) + n_2 - p_2 = b_2$$

$$G_3: \quad f_3(\bar{x}) + n_3 - p_3 = b_3$$

$$G_4: \quad f_4(\bar{x}) + n_4 - p_4 = b_4$$

where $G_i$ denotes goal $i$ . The achievement of these goals, measured in terms of the deviations from their aspired levels, is given by the achievement function (or vector) denoted as $\overline{av}$ where:

$$\overline{av} = \{g_1(n_1,p_1),\ g_2(n_2,p_2),\ g_3(n_3,p_3),\ g_4(n_4,p_4)\} \qquad (9)$$

wherein:

$g_k(n_k,p_k)$ = a function of $n_k$ and $p_k$ , the deviation variables for goal $k$ .

Thus:

$$g_k(n_k,p_k) = \begin{cases} n_k & \text{if the DM wishes } f_k(\bar{x}) \geq b_k \\ p_k & \text{if the DM wishes } f_k(\bar{x}) \leq b_k \\ n_k + p_k & \text{if the DM wishes } f_k(\bar{x}) = b_k \end{cases}$$

Since the goals have been ranked, the method seeks the minimum of $\overline{av}$ (denoted, by $\overrightarrow{av}^*$) . However, the fundamental question with the application of this method to obtain the solution for the (AAP) lies with the way this minimum $\overrightarrow{av}^*$ is sought. That is, given the complicated nature of functional terms $f_i(\bar{x})$ involved in the (AAP), the usual solution procedure via linear programming will not be applicable. Therefore, any solution strategy following the ranked structure and aspiration level established by the DM will work in the general manner specified in the next algorithm.

<u>Algorithm 1</u>

(1) First consider goal $G_1$ alone and seek the set (say $S_1$) of all the alternative layouts attaining this assigned goal for the most prioritized objective with respect to all constraints in the (AAP).

(2) Next find from $S_1$ the set $S_2$ of all the alternative layouts which attain the preassigned goal $G_2$ for the second most prioritized objective and which satisfies all constraints in the (AAP).

(3) The process in (2) is repeated until all the goals are exhausted (Case 1), or only one layout remains, leaving in that case no room for further selection (Case 2).

At termination with Case 1 it can be seen that an attempt has been made to optimize at each goal level. However, the selection of proper aspiration level is vital to this method as it allows some "good" alternative layouts with respect to lower ranked objectives (say objective ranked 3rd and 4th) and not bad with respect to first ranked objectives, to remain available in sets $S_3$ and $S_4$ for investigation.

The pre-emptive goal programming method uses the deviation variables and aspiration level to transform an objective into a goal, for which an attempt is made to minimize the deviation from its achievement. This idea fits particularly well with the so-called "satisfying" concept as advanced by March and Simon (1958) which states that: "Most human decision making, whether organizational or individual, is concerned with the discovery and selection of satisfactory alternatives; only in exceptional cases is it concerned with the discovery and selection of optimal alternatives". Unfortunately with goal programming this selection can continue too far (e.g., even at the end of the solution procedure) as seen above, therefore requiring continuous intervention of the DM in the solution procedure. The nature of the solution procedure desired in the present study requires not more than a one time intervention of the DM. This intervention is also desired only at the batch level, i.e. no type of interactive process is sought.

c) Pre-emptive Priorities Method

The pre-emptive priorities method is usually employed when the objectives are not of comparable importance (i.e. some objectives are by far more important to the DM, than some others) and/or of comparable units (i.e. the objectives involved are of different natures and no conversion to put them in a common unit of measurement is possible). In such situations the objectives can be rank ordered (prioritized) according to their importance and/or contribution in the final solution. The pre-emptive priorities method only requires the DM to rank the different objectives involved in the multicriteria problem. When such ranks are supplied, the problem is solved for one objective at a time in the order of these ranks as in Algorithm 1, but no pre-established goal levels are sought. Instead the best possible and feasible alternatives are sought. In addition, the pre-emptive priorities method allows the use of a strategy appropriate for each objective in the solution process. That is, different solution methods (i.e., exacts or heuristics) can be used separately as appropriate when dealing with each objective of the multicriteria optimization problem.

Clearly the nature of the objectives involved in the multiobjective expression (7) and the above flexibilities of the pre-emptive priorities method make this method the best for use to solve the (AAP). The DM only has to rank all the four objectives in the decreasing order of their priorities. The pre-emptive priorities method applied to the

(AAP) works in the following manner:

Algorithm 2

(1) Consider the first/next objective according to DM's rank order and find the set $S_i$ (for objective $i$ being considered, $S_i$ is inclusive in $S_{i-1}$, $i=1,2,\ldots,4$) of all the alternative layouts which minimize this objective subject to all constraints in the (AAP).

(2) Repeat the above step until all the objectives are optimized or only one layout alternative is left, leaving no further selection possible.

### 4.3.2 Solution Method to the (AAP)

Suppose a DM has given consideration to the nature of the four objectives in the expression 3, 4, 5 and 6 with respect to the layout problem descriptions. The ranking of the objectives in Table 5 has resulted from these considerations.

| rank order | Nature of the objective |
|---|---|
| 1 | Arrangement with minimum cost of violation |
| 2 | Arrangement with minimum number of intersections between the arrows |
| 3 | Arrangement with minimum sum of lengths of arrow in picture |
|  | Arrangement with minimum sum of arrow lengths |

Table 5. Rank Order of the Objectives in the (AAP)

The application of Algorithm 2 to solve the (AAP) resumes to optimize separately four objectives in the sequence specified by the rank order in Table 5. The entire feasible region is considered when optimizing the first objective but is further restricted for the optimization of every next objective to be the solution set reached at the immediately previous objective. A heuristic procedure called the Swinging Algorithm is used to solve the (AAP) using the general idea of Algorithm 2 and the above considerations. The following definitions are needed to understand the procedure steps.

Definition 4.1. The expression $X_{ij} = 1$ defines the assignment of internal point $i$ to label slot $j$ $(i=1,...,N; j=1,...,M)$. Its graphical equivalence corresponds to drawing an arrow from label slot $j$ to internal point $i$. It is assumed $M \geq N$ (See Section 4.3.3) and $(M-N)$ fictitious internal points exist.

Let $LZ_i$ denote the limit zone of $X_{ij}$, that is the set of all label slots in the neighborhood of label slot $j$ to which internal point $i$ can be reassigned without perturbing the existing clockwise order.

Let $U_i$ $(L_i)$ denote the upper (lower) bound of $X_{ij}$, that is, $U_i$ $(L_i)$ is the extreme element of $LZ_i$ in the clockwise (counter-clockwise) direction.

Let $D$ denote a vector of length $M$ used to store the temporary value of distances from an internal point $i$ to each label slot $j$ $(j=1,M)$. $SVD_i$ is a column vector of length $M$ used to store the indices of $D$ when the entries in $D$ are sorted in increasing order.

Let $\bar{D}$ denote a vector of length $M$ used to store the temporary values of distances from internal point $i$ to the intersections of the supporting arrows of $X_{ij} = 1$ with the border of picture between point $i$ and label slot $j$. $\overline{SVD}_i$ is a column vector of length $M$ used to store the indices of $\bar{D}$ when the entries in $\bar{D}$ are sorted in increasing order.

Let $ALT_i$ denote a vector of entries $(0,1,2,\ldots,etc.)$ to identify the indices in $\overline{SVD}_i$ which correspond to alternative equal values in $\bar{D}_i$ (i.e., 0 for elements which do not have any alternative, 1 for first set of alternatives, 2 for second set of alternatives, ... etc.)

Let MINT be an NXN matrix of intersection between the pairs $(X_{ij}=1, X_{k\ell}=1\ i,k=1,\ldots,N,\ i\neq k,\ j.\ell=1,\ldots,M,\ j\neq\ell)$. The entries in this matrix are all of value <u>0 or 1</u>. An entry $(i,k)$ is of value 1 if assignments $X_{ij} = 1$ and $X_{k\ell}=1$ intersect, otherwise it is of value 0.

The steps of the <u>Swinging Algorithm</u> are given below. An illustrative example follows. Detailed flowcharts are seen in <u>Appendix C2</u>.

I. <u>Finding a Feasible Assignment Arrangement</u> (FAA)

<u>Step 0</u>. Set $i=1, N$ for $j=1, M$. Set $X_{ij}=0$, compute $\bar{D}$, D and initialize $\overline{SVD}_i$, $ALT_i$ and $SVD_i$ (equal distances are arbitrarily decided in this process).[1] Let $i = 1$ NLS = M (where NLS denotes the current number of available label slots). Go to Step 1.

[1] Two distances from the same internal points are assumed equal if their absolute difference is $< \alpha$, where $\alpha$ can set at any desired value.

Step 1. Set $X_{ij} = 1$ where $j$ is the first entry in $\overline{SVD}_i$ . Let NLS = NLS-1; if NLS > N-1 , go to step 2; otherwise go to step 3.

Step 2. Set i=i+1, check $\overline{SVD}_i$ and get first $j$ such that $j \in \overline{SVD}_i$ and the followings are satisfied.

(a) N-i number of label slots will still remain available for assignment if $X_{ij} = 1$,

(b) the set of all js such that $X_{ij} = 1$ form a clockwise order.

Set $X_{ij} = 1$ . If i = N , go to Step 4; otherwise update NLS by subtracting the number of label slots just rendered unavailable by this assignment. Go to Step 3.

Step 3. If N-i < NLS go to repeat from step 2; otherwise for i=i+1,...,N set $X_{ij} = 1$ such that:

(a) label slot $j$ is available for assignment,

(b) all $X_{ij} = 1$ form a clockwise order,

Go to Step 4.

Step 4. Consider all pairs $\{(X_{ij} = 1, X_{k\ell}=1); i=1,\dots,N ; k=2,\dots, N-1; j=1,\dots,M, \ell=1,\dots,M ; i\neq k , j\neq\ell\}$ to initialize MINT and evaluate NX (the total number of intersection(s)).[2] If NX = 0, the current solution $(X_{ij} = 1; i=1, N,j=1, M)$ is optimal with respect to objectives 1 and 2 in Table 5; go to part III. If $NX \neq 0$, $(X_{ij} = 1; i=1,N, j=1,M)$ is optimal with respect to objective 1; go to part II.

[2] The intersection of each pair of lines is counted only once. The maximum possible number of intersections is: N+(N-1) + (N-2) + ... + 1 = N(N-1)/2 .

II. Finding Minimum Intersection Assignment Arrangement (MIAA)

Step 0. For each $X_{ij} = 1$ $(i=1,N, j=1,M)$ from part I, initialize the parameters to identify the exchange performed in the immediate previous iteration OLD(1) = 0, OLD(2) = 0, initialize the delimiters of $LZ_i(L_i, U_i)$. Set NEX = 0, $NEX_o = 0$, $NX_o = NX$, NRD = 0, i=N, MOVE = 1, q = 1 and go to Step 1.

Step 1. For i being considered, check one of the following:

(a) If OLD(1) = i and OLD(2) = q -1 go to step 3.

(b) Consider $LZ_i$ and if $L_i = U_i$ go to Step 3.

(c) Consider row i of MINT and evaluate $NNX_i$ (the number of non-zero elements in row i ). If $NNX_i = 0$ go to Step 4; otherwise go to Step 2.

Step 2. Get first $\ell$ $LZ_i$ starting with $\ell = U_i(\ell=L_i)$ if $j = L_i$ $(j=U_i)$ and counter-clockwise (clockwise) to $L_i(U_i)$ such that a fictitious $X_{k\ell}=1$ (that is $k > N$) can be exchanged with $X_{ij} = 1$ to provoke $I_i$ or less number of intersections on assignment $X_{i\ell} = 1$ (where $I_i = NNX_i\text{-}NRD$; $I_i = NNX_i$ if $I_i < 0$). If such $\ell$ is found go to Step 5; otherwise go to Step 3.

Step 3. Proceed with the following checks:

(a) i = 0, set i = 2, MOVE = 2, q = q + 1 and go to repeat from Step 1.

(b) If $i \leq N$ and MOVE = 1, set i = i - 1. If i = 0 go to check 3(a); otherwise go to repeat from Step 1.

(c) If $i \leq N$ and MOVE = 2, set $i = i + 1$. If $i > N$ go to check 3(d); otherwise go to repeat from step 1.

(d) If $i > N$ set $i = N - 1$, MOVE = 1, $q = q + 1$ and go to repeat from step 1.

Step 4. Proceed with the following checks:

(a) If $L_i = U_i$ , then $LZ_i = \{j\}$ need not be explored; go to step 3.

(b) If $j \neq L_i$ and $j \neq U_i$ , the current $X_{ij} = 1$ in the $NNX_i = 0$ is not blocking any other assignment from improving, go to step 3; otherwise go to step 2.

Step 5. Set $X_{ij} = 0$, $X_{kj} = 1$, $X_{i\ell} = 1$, OLD(1) = i, OLD(2) = q , update $LZ_i$, MINT, and NX . If NX = 0 go to Step 7; otherwise set NEX = NEX + 1 . If $NX < NX_o$ , .set $NX_o = NX$ , $NEX_o = NEX$ and go to step 3. If $(NEX-NEX_o) > N$, a " Lock" is formed in the pairwise exchange procedure, go to step 6; otherwise go to step 3.

Step 6. If NRD = Max($NNX_i$; i=1,N) go to Step 8. Otherwise set NRD = Min (NRD+1, Max ($NNX_i$, i=1,N)). Set i = N and go to repeat from step 1.

Step 7. The current solution ($X_{ij}$ = 1, i=1, N,j=1,M) is optimal with respect to the first objectives 1 and 2, go to part III.

Step 8. The current solution ($X_{ij}$ = 1; i=1, N, j=1,M) is optimal with respect to objective 1 and "sub-optimal" with respect to objective 2. The value of this objective (number of intersections) is NX .

## III. Minimizing The "Total Distance" Of The Assignments In The Picture (MTDAP)

Step 0. Set $i = N$, $MOVE = 1$, $q = 0$, $OLD(1) = 0$, $OLD(2) = 0$, $NX_0 = NX$ consider the vectors $\overline{SVD}_i$ $(i=1,N)$ as established in part I, and go to step 1.

Step 1. Consider $LZ_i$ and if $L_i = U_i$ (no improvement is possible), go to step 2; otherwise get Jmax where $j = \overline{SVD}_i(\text{Jmax})$ and $X_{ij} = 1$. Step $k = 1,\ldots,J_{max}$ and find *first* $= \overline{SVD}_i(k)$ such that $\ell \in LZ_i$ and $X_{r\ell} = 1$, $r > N$. If $k = j_{max}$ (the current assignment is the best in $LZ_i$) go to step 2; otherwise go to step 3.

Step 2. Set $q = q + 1$ and proceed with the following checks:

(a) If $OLD(1) = i$ and $(q-OLD(2)) > 2*N$, go to step 4.

(b) If $i = 0$, set $i = 2$, $MOVE = 2$, and go to repeat from step 1.

(c) If $i \leq N$ and $MOVE = 1$, set $i = i - 1$, if $i = 0$ go to check 2(b), otherwise go to repeat from step 1.

(d) If $i \leq N$ and $MOVE = 2$, set $i = i + 1$. If $i > N$ go to check 2(e); otherwise go to repeat from step 1.

(e) If $i > N$ set $i = N - 1$, $MOVE = 1$, and go to repeat from step 1.

Ste $X_{i\ell} = 1$, $X_{ij} = 0$, $X_{r\ell} = 0$, $X_{rj} = 1$; check all pairs $\{X_{i\ell} = 1$, $X_{nm} = 1$; $n = 1, N$, $m = 1, M$, $n \neq i$, $m \neq \ell\}$ and compute new intersection number $NX$. If $NX > NX_0$ set $X_{ij} = 1$, $X_{i\ell} = 0$, $X_{r\ell} = 1$, $X_{rj} = 0$ and go to next $k$ in step 1; otherwise set $OLD(1) = i$, $OLD(2) = q$, update $LZ_i$; MINT and go to repeat from step 2.

Step 4. Every assignment was considered in the last pass but no exchange was found suitable to improve the objective value being considered. Hence no further reduction of the objective is possible using the present exchange method. The current solution ($X_{ij} = 1, i = 1, N, j = 1, M$) is "sub-optimal" with respect to objective 3. Go to part IV.

## IV. Minimizing The "Total Distance" Of The Assignment (MTDA)

Initialization Step (Step 0).

Set $i = N$, $q = 1$, $OLD(1) = N$, $OLD(2) = 0$, $NX_0 = NX$ and go to the main steps (with $SVD_i(\overline{SVD_i})$ and $ALT_i(i=1,N)$ as established in part I) .

Main Steps

These steps are basically the same steps as in part III with the following modification of step 1.

Step 1. Consider $LZ_i$ and if $L_i = U_i$ (no improvement of objective 4 is possible); go to step 2. Otherwise get $t$ and $\overline{t}$ where $j = SVD_i(t)$ and $j = \overline{SVD}_i(\overline{t})$ . If $\overline{t} = 1$ and/or $ALT_i(\overline{t}) = 0$ , go to step 2. Find first $k = 1, t$ such that $\ell = SVD_i(k)$ and $\ell \in LZ_i$ . If $k = t$ go to step 2; otherwise get $\overline{k} = \overline{SVD}_i(\ell)$; if $\overline{k} > \overline{t}$ and $ALT_i(\overline{t})$[3] $= 0$ go to step 2 .

[3] If $\overline{k} < \overline{t}$ the exchange is only between alternative solutions of objective 3 if such alternative exist. This verifies that the current label slot which will improve the value of objective 4 does not worsen the value of objective 3 before allowing the assignment to that slot.

Also go to step 2 if $ALT_i(\overline{k}) \neq ALT_i(\overline{t})$ ; otherwise go to step 3.[4]

### 4.3.3 Remarks

(a) The Swinging Algorithm steps in part I reduce to a simple one to one assignment scheme if $N = M$, and can still be used to solve the (AAP). However, it will be inefficient as no record keeping is needed in that case. It is assumed that a simple check of $N$ and $M$ will be used prior to using the algorithm. It is clear that when $N > M$ , the problem is infeasible.

(b) A clockwise order between the label slots is referred when describing the steps, but in reality any other order can be used without a modification of the steps described above. However changes may be required in designing and updating processes of $LZ_i(i = 1, N)$ .

(c) When $N < M$ the (AAP) is a combinatorial problem and every combination is not necessarily feasible. The procedure in part I only seeks a feasible arrangement, and $\overline{SVD}_i$ (i=1,N) (rather than $SVD_i$ (i=1,N)) are used as desired by the preemptive priorities in Table 5. Truly any other method select $N$ among $M$ elements which enforces the arrangement and the other constraints in the (AAP) is also valid.

[4] The exchange to be attempted at step 3 will be carried out if only it is also verified not to worsen the arrangement and the intersection situation.

(d) Steps 2, 3 and 4 in part II resume at finding the label slot among all unoccupied label slots which, if linked to internal point $i$, will render more label slots available for other assignments restricted due to the order (e.g. notably assignment to points $i-1$ or $i+1$) and possibly in worse intersection situations. The operations in step 5 starting with $X_{kj} = 0$, $X_{i\ell} = 1$ where $k > N$ and $\ell \neq j$ were found earlier in step 2, and correspond to pairwise exchanges. Their physical illustrations correspond to omitting the arrow from point $i$ to label slot $j$ and drawing one from point $i$ to label slot $\ell$. More about this is given in Section 4.3.5.

(e) The term "total distance" is used in parts III and IV to indicate an attempt to minimize the sum of the different lengths of the arrows through a minimization of each arrow. Equal preferences are given to every arrow although other (complicated) relationships may have been proper. In addition only one method of exchanging one arrow at time is attempted and no one arrow is allowed to get worse for the improvement of another. Other methods to seek the exchanges of two, three or more combinations of assignments at a time, while maintaining the values of previous objectives from getting worse may result in better objective values of parts III and IV. This argument is also valid for part II.

### 4.3.4 An Illustrative Example

Consider the example problem ($N = 7$ and $M = 20$) shown in Figure 24. The positions of the internal points in the picture and their sequence numbers are assumed random for the purpose of the example. The steps of the procedure for the example of Figure 24 are given below:

### I. Finding An (FAA)

Step 0. $i = 1$ ($\overline{D}$ and $D$ are given in cm)

$\overline{D} = [.9, 1.4, 1.5, 2.0, 2.3, 3.0, 3.4, 4.2, 3.8, 3.8, 4.2, 4.2, 3.3, 2.7, 1.3, 2.0, 1.6, 1.0, .7, .7]^t$ ,

$\overline{SVD}_1 = [19, 20, 1, 18, 15, 2, 3, 17, 4, 16, 5, 14, 6, 7, 9, 10, 8, 11, 12]^t$ and

$ALT_1$[5] $= [1, 1, 0, 0, 0, 0, 0, 0, 2, 2, 0, 0, 0, 0, 3, 3, 4, 4, 4]^t$ .

$D = [3.7, 3.2, 2.9, 3.1, 3.6, 4.4, 5.3, 6.3, 6.5, 6.5, 6.5, 5.4, 4.4, 3.8, 3.1, 3.0, 3.2, 3.8, 3.5, 3.5]^t$ and

$SVD_1 = [3, 16, 4, 15, 2, 17, 19, 20, 5, 1, 14, 18, 6, 13, 7, 12, 8, 9, 10, 11]^t$ .

$i = 2, 7$ : $\overline{SVD}_i$ and $SVD_i$ are similarly obtained. Their values are seen in Appendix C3 and can be omitted in here without loss of continuity.

$NLS = 20$. Go to step 1.

[5] For the purpose of the example the numbers in $\overline{D}$ are rounded to the first decimal in order to create some non zero elements in ALT.

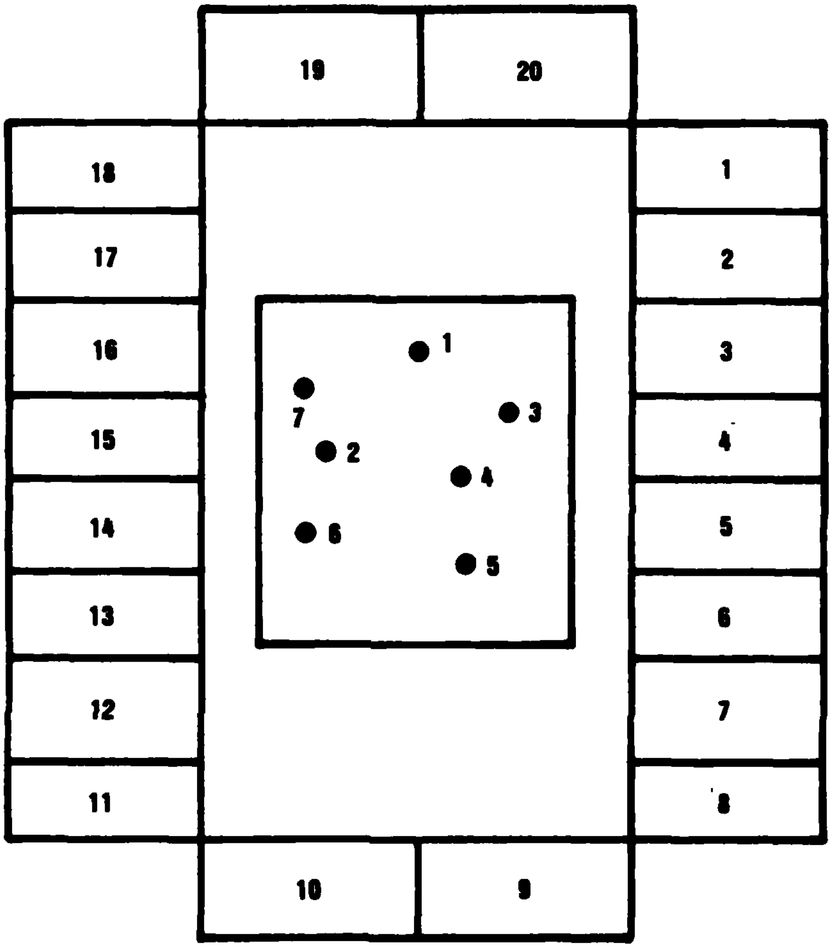


Figure 24. An Illustrative Example

● The internal points are assumed randomly generated.

Step 1[6]. $j = 19$ is first entry in $\overline{SVD}_1$, hence set $X_{1,19} = 1$. NLS = 19 and since this is greater than 6, go to step 2.

Step 2. $i = 2$; $j = 15$ is first entry in $\overline{SVD}_2$ (see Appendix C3) but if $X_{2,15} = 1$ only 3 label slots will remain for assignment of points 3, 4, 5, 6 and 7, consequently the (AAP) constraints are violated because $NLS = 3 < N - 2 = 5$. Hence set $X_{2,13} = 1$, and count 14 label slots rendered unavailable by $X_{2,13} = 1$; set NLS = 5 and go to step 3.

Step 3. $N - 2 = 5 \nless NLS$ therefore set $X_{3,14} = 1$; $X_{4,15} = 1$, $X_{5,16} = 1$ $X_{6,17} = 1$ and $X_{7,18} = 1$. Go to step 4.

Step 4. The symmetric matrix of intersection obtained by a "one-half" examination of every pair of the above assignments is given below:

$$MINT = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

[6] Note: $j = 20$, the second entry in $\overline{SVD}_1$ could also have been selected here, and $X_{1,20} = 1$. The alternative choices and their related problems are the subject of the discussion in the next sections.

NX = 10 and the corresponding graphical presentation of this solution is shown in Figure 25. Since NX $\neq 0$ the current solution is only optimal with respect to objective 1. In the following part alternative optimal solutions will be generated in order to decrease the current value of NX .

I. Finding a (MIAA)

Step 0. OLD(1) = 0, OLD(2) = 0.

Set the delimiters $L_i$ and $U_i$ of $LZ_i(i=1,N)$ as

$$\begin{array}{lcccccccc} L & = & 19 & 20 & 14 & 15 & 16 & 17 & 18 \\ U & = & 12 & 13 & 14 & 15 & 16 & 17 & 18 \end{array} ;$$

where each column i delimits the set $LZ_i$ (in clockwise order).

NEX = 0, $NEX_0$ = 0, NX = 10, NRD = 0, i = 7

MOVE = 1, q = 1; go to step 1.

Step 1. Since $L_7 = U_7$ go to step 3.

Step 3b. Now i = 7 and MOVE = 1, hence i = 6, go to step 1.

Step 1b. Since $L_6 = U_6$ go to step 3.

Step 3b. Now i = 6 and MOVE = 1, hence i = 5; go to step 1.

Step 1b. Since $L_5 = U_5$ go to step 3.

Step 3b. Now i = 5 and MOVE = 1, hence i = 4; go to step 1.

Step 1b. Since $L_4 = U_4$ go to step 3.

Step 3b. Now i = 4 and MOVE = 1, hence i = 3; go to step 1.

Step 1. Since $L_3 = U_3$ go to step 3.

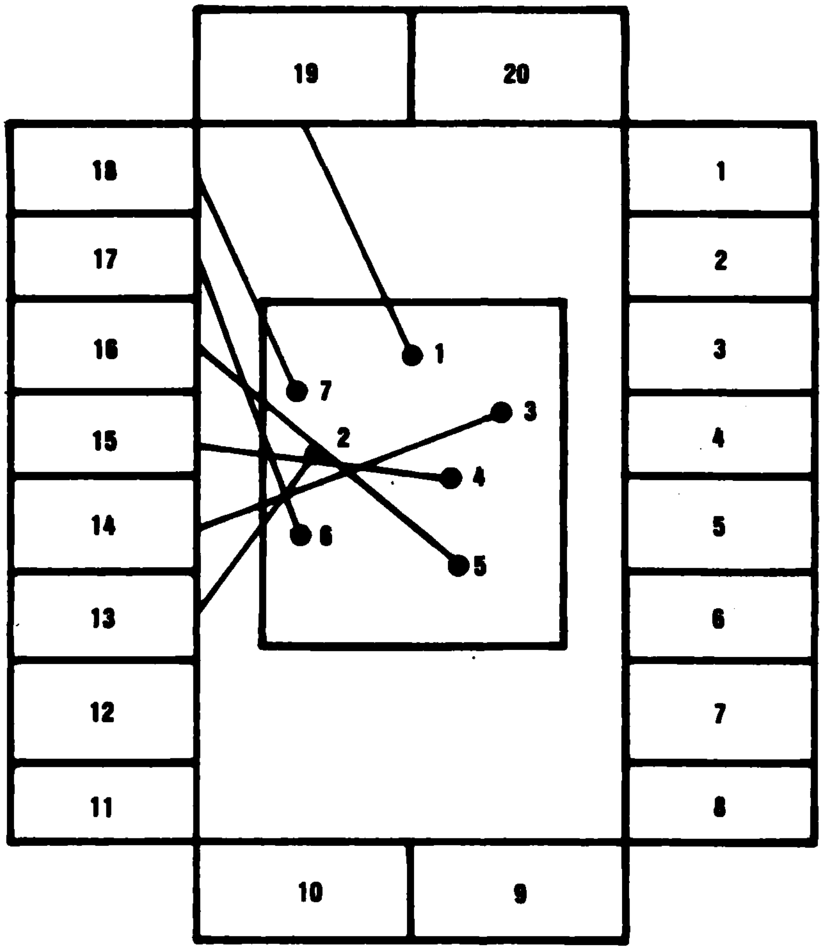


Figure 25. Solution of the FAA procedure

Step 3b. Now $i = 3$ and MOVE = 1, hence $i = 2$; go to step 1.

Step 1c. Since $NNX_2 = \sum_{i=1}^{7} MINT(2,i) = 4$ go to step 2.

Step 2. For $X_{2,13} = 1$ and $U_2 = 13$, first $\ell \in LZ_2$ (starting from $L_2 = 20$) is $\ell = 20$ ; if assignment $X_{2,20} = 1$ then the number of intersections which involve $X_{2,20} = 1$ is $3 < I_2 = 4$; therefore $\ell = 20$ and go to step 5.

Step 5. Now the fictitious assignment $X_{k,20}$ is exchanged with $X_{2,13} = 1$, hence $X_{2,20} = 1$, $X_{2,13} = 0$, $X_{k,20} = 0$, $X_{k,13} = 1$ and the next updatings follow:

- OLD(1) = 2, OLD(2) = 1;

- entry of point 2 and of its immediate neighbors 1 and 3 change and the set $LZ_s$ become:

$$\begin{array}{llllllll} L & = 19 & 20 & 1 & 15 & 16 & 17 & 18 \\ U & = 19 & 13 & 14 & 15 & 16 & 17 & 18 \end{array} ;$$

- the row and column 2 of MINT change as shown below

$$MINT = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- currently NX = 9.
- NX ≠ 0 , hence NEX = 1, $NEX_0$ = 1, $NX_0$ = 9; go to step 3.

Step 3b. Now i = 2 and MOVE = 1, hence i = 1; go to step 1.

Step 1b. Since $L_1 = U_1$ go to step 3. This is the end of the first iteration, a counter-clockwise swing (MOVE = 1) was done. The current non-fictitious assignments are shown in Figure 26.

Step 3b. Now i = 1 and MOVE = 1, hence i = 0; go to (a).

Step 3a. Now i = 0 and MOVE = 1, hence i = 2, MOVE = 2, q = 2 (begin second iteration) go to step 1.

Step 1a. OLD(1) = 2 and OLD(2) = 1, therefore go to step 3.

Step 3c. Now i = 2 and MOVE = 2, hence i = 3, go to step 1.

Step 1c. Since $NNX_3 = 3$, go to step 2.

Step 2. For $X_{3,14} = 1$, $U_3 = 14$, first $\ell = 1$; if $X_{3,1} = 1$, the number of intersections on $X_{3,1}$ is $0 < I_3 = 3$; therefore $\ell = 1$ ; go to step 5.

Step 5. The fictitious assignment $X_{k,1} = 1$ is exchanged with $X_{3,14} = 1$, hence $X_{3,1} = 1$, $X_{3,14} = 0$, $X_{k,1} = 0$, $X_{k,14} = 1$ and the next updatings follow:

- OLD(1) = 3, OLD(2) = 2;

$$\begin{array}{lcccccccc} L & = & 19 & 20 & 1 & 2 & 16 & 17 & 18 \\ & & & & & & & & & ; \\ U & = & 19 & 20 & 14 & 15 & 16 & 17 & 18 \end{array}$$

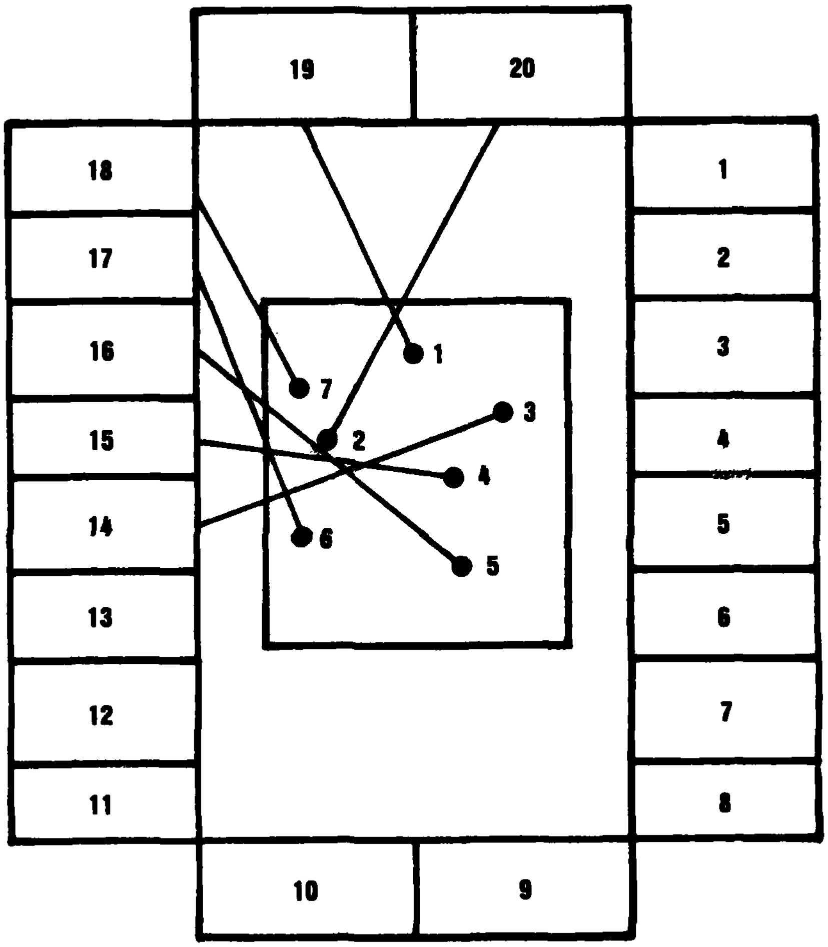


Figure 26. Solution at the end of the first swing (move = 1) in the MIAA procedure

$$\text{MINT} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- currently $NX = 6$

- $NX \neq 0$ hence $NEX = 2$, $NEX_o = 2$, $NX_o = 6$ ; go to step 3.

Step 3c. $i = 3$ and $MOVE = 2$, hence $i = 4$; go to step 1.

Step 1c. Since $NNX_4 = 3$, go to step 2.

Step 2. For $X_{4,15} = 1$, $U_4 = 15$, first $\ell = 2$; if $X_{4,2} = 1$, the number of intersections on $X_{4,2}$ is $1 < I_4 = 3$; therefore set $\ell = 2$ and go to step 5.

Step 5. The fictitious assignment $X_{k,2} = 1$ is exchanged with $X_{4,5} = 1$, hence $X_{4,2} = 1$, $X_{3,14} = 0$, $X_{k,2} = 0$, $X_{k,15} = 1$ and the next updatings follow:

- $OLD(1) = 4$

$$\begin{array}{lllllllll} L & = & 19 & 20 & 1 & 2 & 3 & 17 & 18 \\ U & = & 19 & 20 & 1 & 15 & 16 & 17 & 18 \end{array} \quad ;$$

$$\text{MINT} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- currently $\underline{NX = 4}$

- $NX \neq 0$, $NEX = 3$, $NEX_0 = 3$, $NX_0 = 3$; go to step 3.

Step 3c. $i = 4$ and $MOVE = 2$, hence $i = 4$, go to step 1.

Step 1c. Since $NNX_5 = 2$, go to step 2.

Step 2. For $X_{5,16} = 1$, $U_5 = 16$, first $\ell = 3$; if $X_{5,3} = 1$, the number of intersections on $X_{5,3}$ is $0 < I_5 = 2$ therefore $\ell = 3$; go to step 5.

Step 5. The fictitious assignment $X_{k,3} = 1$ is exchanged with $X_{5,15} = 1$, hence $X_{5,3} = 1$, $X_{5,16} = 0$, $X_{k,3} = 0$, $X_{k,15} = 1$ and the next updatings follow:

- OLD(1) = 5

$$\begin{array}{lcccccccc} L & = & 19 & 20 & 1 & 2 & 3 & 4 & 18 \\ & & & & & & & & & ; \\ U & = & 19 & 20 & 1 & 2 & 16 & 17 & 18 \end{array}$$

$$\text{MINT} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- Currently $\underline{NX = 2}$

- $NX \neq 0$, hence $NEX = 4$, $NEX_o = 4$, $NX_o = 2$ go to step 3.

Step 3c. $i = 5$ and $MOVE = 2$, hence $i = 6$, go to step 1.

Step 1c. Now $NNX_6 = 0$ go to step 4.

Step 4b. For $X_{6,17} = 1$, $U_6 = 17$ go to step 2.

Step 2. First $\ell = 7$; if $X_{6,7} = 1$, the number of intersections on $X_{6,7} = 0$ $(I_6 = 0)$, therefore $\ell = 7$, go to step 5.

Step 5. $X_{k,7} = 1$ is exchanged with $X_{6,17} = 1$, hence $X_{6,7} = 1$, $X_{6,17} = 0$, $X_{k,7} = 0$, $X_{k,17} = 1$ and properly update OLD, $LZ_5$, MINT, NX as follows:

- OLD(1) = 6

$$L = 19 \quad 20 \quad 1 \quad 2 \quad 3 \quad 4 \quad 8$$

;

$$U = 19 \quad 20 \quad 1 \quad 2 \quad 6 \quad 17 \quad 18$$

MINT is unchanged.

- Currently $\underline{NX = 2}$

- NEX = 5 and NX ; (NEX - $NEX_0$) = 1

no "Lock" is yet present; go to step 3.

Step 3. i = 6 and MOVE = 2, hence i = 7; go to step 1.

Step 1c. $NNX_7 = 0$ go to step 4.

Step 4. For $X_{7,18} = 1$, $U_7 = 18$; go to step 2.

Step 2. First $\ell = 11$; if $X_{7,11} = 1$, the number of intersection on $X_{7,11}$ is $0 = I_7$, hence $\ell = 11$; go to step 5.

Step 5. $X_{k,11} = 1$ is exchanged with $X_{7,18} = 1$ , hence $X_{7,11} = 1$, $X_{7,18} = 0$, $X_{k,11} = 0$, $X_{k,18} = 1$ and properly update OLD, $LZ_5$, MINT, NX as follows:

- OLD(1) = 7

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| L | = | 19 | 20 | 1 | 2 | 3 | 4 | 8 |
| U | = | 19 | 20 | 1 | 2 | 6 | 10 | 18 |

MINT is unchanged

- Currently NX = 2

- NEX = 6; $NX_0$ = NX and (NEX - $NEX_0$) = 2 < 7, go to step 3.

This is the end of second iteration; a clockwise swing (MOVE = 2) was done. The current non-fictitious assignments are shown in Figure 27.

Step 3c. i = 7 and MOVE = 2 hence i = 8.

Step 3d. i = 6, MOVE = 1, q = 3 go to step 1.

Step 1c. $NNX_6 = 0$ go to step 4.

Step 4b. For $X_{6,7} = 1$, $L_i = 4$, $U_6 = 10$; since $NNX_6 = 0$, go to step 3.

Step 3b. i = 5, go to step 1.

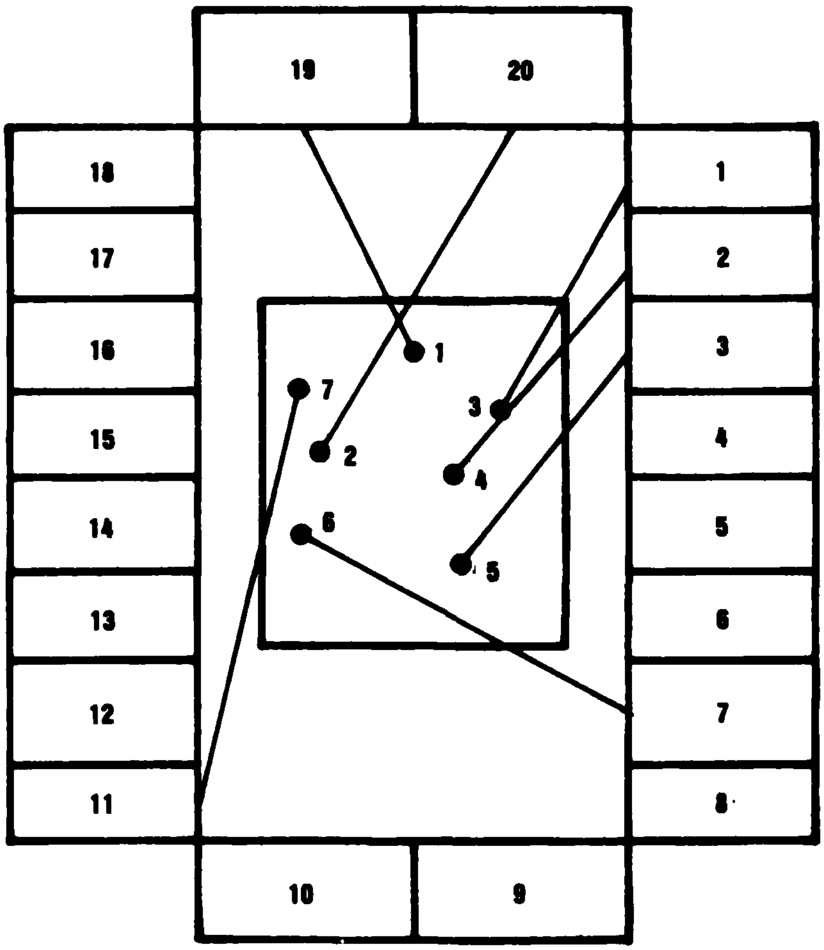


Figure 27. Solution at the end of the second swing (MOVE = 2) in the MIAA procedure

Step 1c. $NNX_5 = 0$, go to step 4.

Step 4b. For $X_{5,3} = 1$, $L_5 = 3$, go to step 2 (as $NX \neq 0$, $X_{5,3} = 1$, may be blocking the way to an $X_{i,n} = 1$, $i \leq N$ from an improving exchange).

Step 2. For $X_{5,3} = 1$ and $L_5 = 3$, first $\ell = 6$ and $X_{5,6} = 1$ will not worsen NX, go to step 5.

Step 5. Exchange $X_{k,6} = 1$ with $X_{5,3} = 1$ that is set $X_{5,6} = 1$, $X_{5,3} = 0$, $X_{k,6} = 0$, $X_{k,3} = 1$. Perform the following updatings:

- OLD(1) = 5, OLD(2) = 3

$$\begin{array}{ccccccccc} L & = & 19 & 20 & 1 & 2 & 3 & 7 & 8 \\ & & & & & & & & ; \\ U & = & 19 & 20 & 1 & 2 & 6 & 10 & 18 \end{array}$$

MINT is unchanged

- NX = 2 is unchanged
- NEX = 7, and $(NEX-NEX_o) = 3$, go to step 3.

Step 3b. $i = 4$, go to step 1.

Step 1c. $NNX_4 = 1$ go to step 2.

Step 2. For $X_{4,2} = 1$ and $L_4 = 2$, first $\ell = 5$ will result in $0 < I_4 = 1$ intersection. Go to step 5.

Step 5. Exchange $X_{k,5} = 1$ with $X_{4,2} = 1$ and set $X_{4,5} = 1$, $X_{4,2} = 0$, $X_{k,5} = 0$, $X_{k,2} = 1$. Perform the following updatings:

- OLD(1) = 4,

$$\begin{array}{ccccccccc} L & = & 19 & 20 & 1 & 2 & 6 & 7 & 8 \\ & & & & & & & & ; \\ U & = & 19 & 20 & 4 & 5 & 6 & 10 & 18 \end{array}$$

$$\text{MINT} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- Currently $NX = 1$

$NX \neq 0$, $NEX = 9$, $NEX_0 = 9$, $NX_0 = 1$ , go to step 3.

Step 3b. $i = 3$, go to step 1.

Step 1c. $NNX_3 = 0$, go to step 4.

Step 4b. For $X_{3,1} = 1$, $L_3 = 1$ go to step 2 (as $NX \neq 0$, $X_{3,1} = 1$ may be blocking the way to an $X_{i,n} = 1$, $i \leq N$ from an improving exchange).

Step 2. For $X_{3,1} = 1$ and $L_3 = 1$ first $\ell = 4$ and $X_{3,4} = 1$ will not worsen $NX$, go to step 5.

Step 5. Exchange $X_{k,4} = 1$ with $X_{3,1} = 1$ that is set $X_{3,4} = 1$, $X_{3,1} = 0$, $X_{k,4} = 0$, $X_{k,1} = 1$ . Perform the following updatings:

- $OLD(1) = 3$,

$$\begin{array}{l} L = 19 \quad 20 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad ; \\ U = 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 10 \quad 18 \end{array}$$

MINT is unchanged

- $NX = 1$ is unchanged

- $NEX = 10$, $NX = NX_0\ (NEX\text{-}NEX_0) = 1$, go to step 3.

Step 3b. $i = 2$, go to step 1.

Step 1c. $NNX_2 = 1$, go to step 2.

Step 2. First $\ell = 3$, if $X_{2,3} = 1$, the number of intersections on $X_{2,6}$ is 0 ($I_6 = 1$), therefore $\ell = 3$, go to step 5.

Step 5. Exchange $X_{k,3} = 1$ with $X_{2,20} = 1$ that is set $X_{2,3} = 1$, $X_{2,20} = 0$, $X_{k,3} = 0$, $X_{k,20} = 1$. Perform the following updatings:

- OLD(1) = 2.

$$\begin{array}{lcccccccc} L & = & 19 & 20 & 4 & 5 & 6 & 7 & 8 \\ & & & & & & & & ; \\ U & = & 19 & 3 & 4 & 5 & 6 & 10 & 18 \end{array}$$

- MINT is a zero-matrix,
- currently $NX = 0$.
- Since $NX = 0$ go to step 7.

Step 7. The current solution ($X_{1,19} = 1$, $X_{2,3} = 1$, $X_{3,4} = 1$, $X_{4,5} = 1$, $X_{5,6} = 1$, $X_{6,7} = 1$, $X_{7,11} = 1$) forms a clockwise arrangement, in addition $NX = 0$, therefore it is optimal to both objectives 1 and 2. The non-fictitious assignments are seen in Figure 28.

Given $N < M$, alternative optimal solutions with respect to these two objectives can exist. The next parts of the heuristic will use the same sequence of forward and backward swings to generate the optimal alternative solutions which will improve the total distance crossed in the picture (MTDAP) and the overall total distance of the arrows (MTDA).

## III. Finding a MTDAP

Step 0. $i = 7$, MOVE = 1, $q = 1$, OLD(1) = 0, OLD(2) = 0, $NX_0 = NX = 0$ consider $\overline{SVD}_7$, in Appendix C3 and go to step 1.

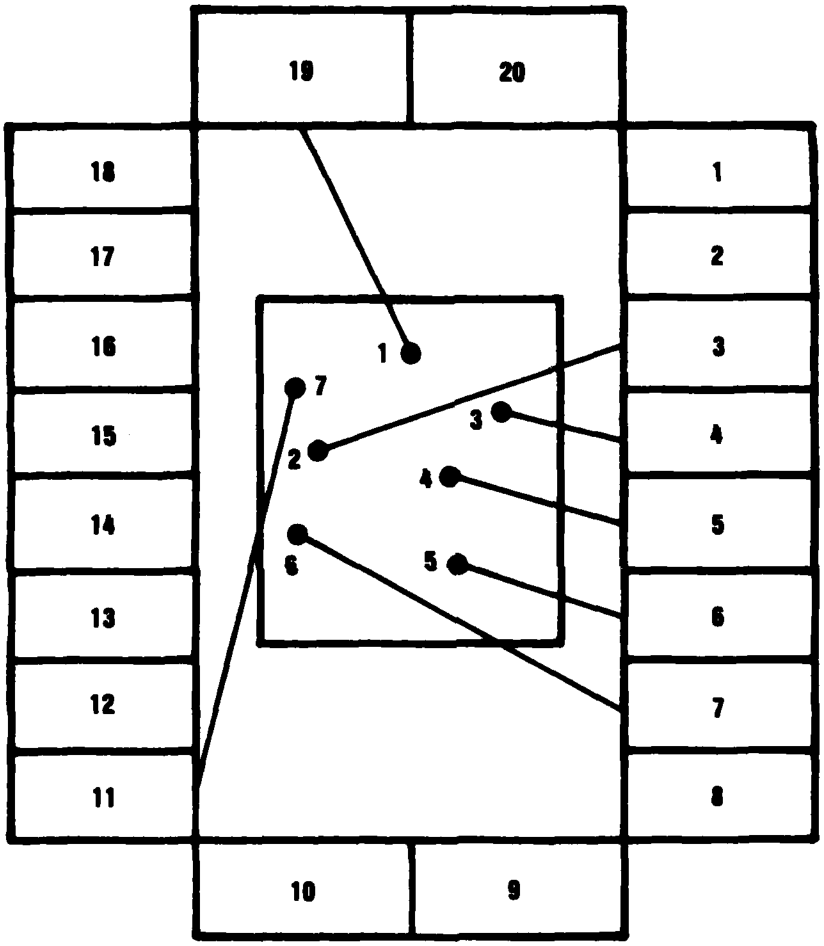


Figure 28. Solution at the end of the MIAA procedure. Notice that NX = 0.

Step 1. For $i = 7$, currently $J_{max} = 13$ since $\overline{SVD}_7(13) = 11$; for $k = 1, 11$; first $\ell = 15 = SVD_7(1)$ and $\ell = 15 \in LZ_7$ ; (that is $X_{7,15}$ causes the shortest cross in the picture from point 7). Go to step 3.

Step 3. $X_{7,15} = 1$, $X_{7,11} = 0$ , also $NX = NX_0 = 0$.
OLD(1) = 7, OLD(2) = 1;

$$L = 16 \quad 20 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8$$
;
$$U = 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 14 \quad 18$$

MINT remains a zero matrix; go to step 2.

Step 2. $q = 2$, $(q - OLD(2)) = 1$

Step 2c. $i = 7$ and MOVE = 1, set $i = 6$ and go to step 1.

Step 1. For $i = 6$ currently $J_{max} = 11$ since $\overline{SVD}_6(11) = 7$ (see Appendix C3); for $k = 1, 11$ first $\ell = 14$ and $\ell = 14 \in LZ_6$ . Go to step 3.

Step 3. $X_{6,14} = 1$ and $X_{6,7} = 0$, also $NX = NX_0 = 0$.
- OLD(1) = 6, QLD(2) = 2;

$$L = 16 \quad 20 \quad 4 \quad 5 \quad 6 \quad 7 \quad 15$$
;
$$U = 2 \quad 3 \quad 4 \quad 5 \quad 13 \quad 14 \quad 18$$

- MINT remains a zero matrix; go to step 2.

Step 2. $q = 3$, $(q - OLD(2)) = 1$.

Step 2c. $i = 6$ and MOVE = 1, set $i = 5$ and go to step 1.

Step 1. For $i = 5$, currently $J_{max} = 5$ since $\overline{SVD}_5(5) = 6$. For $k = 1, 6$ first $\ell = 9$ and $\ell \in LZ_5$ . Go to step 3.

Step 3. $X_{5,9} = 1$ and $X_{5,6} = 0$, also $NX = NX_0 = 0$ .
- OLD(1) = 5, OLD(2) = 3;

$$\begin{array}{lccccccc} L & = & 16 & 20 & 4 & 5 & 6 & 10 & 15 \\ & & & & & & & & & ; \\ U & = & 2 & 3 & 4 & 8 & 13 & 14 & 18 \end{array}$$

- MINT remains a zero matrix; go to step 2.

Step 2. $q = 4$, $(q - OLD(2)) = 1$

Step 2c. $i = 5$ and MOVE = 1, set $i = 4$ and go to step 1.

Step 1. For $i = 4$, currently $J_{max} = 2$ since $\overline{SVD}_4(2) = 5$; for $k = 1$, $\ell = \overline{SVD}_4(k) = 4 \notin LZ_4$ . Next $k = 2 = J_{max}$ , therefore $X_{4,5} = 1$ remains, go to step 2.

Step 2. $q = 5$, $(q - OLD(2)) = 2$.

Step 2c. $i = 4$ and MOVE = 1 set $i = 3$ and go to step 1.

Step 1. For $i = 3$; $L_3 = U_3 = 4$ (no improvement is possible) go to step 2.

Step 2. $q = 6$ and $(q - OLD(2)) = 3$.

Step 2c. $i = 3$ and MOVE = 1, set $i = 2$ and go to step 1.

Step 1. For $i = 2$, currently $J_{max} = 15$ since $\overline{SVD}_2(15) = 3$. For $k = 1,2,\ldots,14$ First $\ell = 1$ as $\ell = 1 = \overline{SVD}_2(10) \in LZ_2$ . go to step 3.

Step 3. For $X_{2,1} = 1$ and $X_{2,3} = 0$, $NX = 1 > NX_0 = 0$ therefore $X_{2,1} = 0$ and $X_{2,3} = 1$, go to step 2.

Step 2. $q = 7$ and $(q - OLD(2)) = 4$.

Step 2c. $i = 2$ and MOVE = 1, set $i = 1$ and go to step 1.

Step 1. For $i = 1$, $J_{max} = 1$ since $\overline{SVD}_1(1) = 19$; currently point 1 is being assigned to its best slot with respect to objective 3 $(k = 1 = J_{max})$; go to step 2.

Step 2. $q = 8$ and $(q - OLD(2)) = 5$.

Step 2c. $i = 1$ and MOVE = 1, set $i = 0$, go to step 2b.

Step 2b. Set $i = 2$, MOVE = 2 and go to step 1.

Step 1. For $i = 2$, currently $J_{max} = 15$ since $\overline{SVD}_2(15) = 3$ . For $k = 1,2,\ldots,14$, first $\ell = 1$ as $\ell = 1 = \overline{SVD}_2(10) \in LZ_2$ . Go to step 3.

Step 3. For $X_{2,1} = 1$ and $X_{2,3} = 0$, $NX = 1 > NX_0 = 0$, therefore $X_{2,1} = 0$ and $X_{2,3} = 1$; go to step 2.

Step 2. $q = 8$ and $(q - OLD(2)) = 6$.

Step 2d. $i = 2$, MOVE = 2, set $i = 3$, go to step 1.

Step 1. For $i = 3$; $L_3 = U_3 = 3$, go to step 2.

Step 2. $q = 9$, $(q - OLD(2)) = 7$.

Step 2d. $i = 3$, MOVE = 2, set $i = 4$, go to step 1.

Step 1. For $i = 4$, currently $J_{max} = 2$ since $\overline{SVD}_3(2) = 5$. For $k = 1$, $\ell = \overline{SVD}_4(k) = 4 \notin LZ_4$ ; go to step 2.

Step 2. $q = 10$, $(q - OLD(2)) = 8$.

Step 2d. $i = 4$, MOVE = 2, set $i = 5$, go to step 1.

Step 1. For $i = 5$, $J_{max} = 1$, since $\overline{SVD}_5(1) = 9$; currently point 5 is at its best assignment, go to step 2.

Step 2. $q = 11$, $(q - OLD(2)) = 9$.

Step 2d. $i = 5$, MOVE = 2 set $i = 6$ go to step 1.

Step 1. For $i = 6$, $J_{max} = 1$ since $\overline{SVD}_6(1) = 14$; currently point 6 is at its best assignment, go to step 2.

Step 2. $q = 12$, $(q - OLD(2)) = 10$.

Step 2d. $i = 6$, MOVE = 2, set $i = 7$, go to step 1.

Step 1. For $i = 7$, $J_{max} = 1$ since $\overline{SVD}_7(1) = 15$; currently point 7 is at its best assignment, go to step 2.

Step 2. $q = 13$, $(q - OLD(2)) = 11$.

Step 2d. $i = 7$, MOVE = 2, set $i = 8$, go to step 2e.

Step 2e. Set $i = 6$, MOVE = 1, go to step 1.

Step 1. For $i = 6$, $J_{max} = 1$ since $\overline{SVD}_6(1) = 14$; currently point 6 is at its best assignment, go to step 2.

Step 2. $q = 14$, $(q - OLD(2)) = 12$.

Step 2b. $i = 6$, MOVE = 1, set $i = 5$, go to step 1.

Step 1. For $i = 5$, $J_{max} = 1$, since $\overline{SVD}_5(1) = 9$; currently point 5 is at its best assignment, go to step 2.

Step 2. $q = 15$, $(g = OLD(2)) = 13$.

Step 2b. $i = 5$, MOVE = 1, set $i = 4$, go to step 1.

Step 1. For $i = 4$, currently $J_{max} = 2$ since $\overline{SVD}_4(2) = 5$; for $k = 1$, $\ell = \overline{SVD}_4(k) = 4 \notin LZ_4$ . Next $k = 2 = J_{max}$, therefore $X_{4,5} = 1$ remains. Go to step 2.

Step 2. $q = 16$, $(q - OLD(2)) = 14$; go to step 4.

Step 4. The current solution ($X_{1,19} = 1$, $X_{2,3} = 1$, $X_{3,4} = 1$, $X_{4,5} = 1$, $X_{5,9} = 1$, $X_{6,14} = 1$, $X_{7,15} = 1$) seen in Figure 29 is "sub-optimal" with respect to objective 3, go to Part IV.

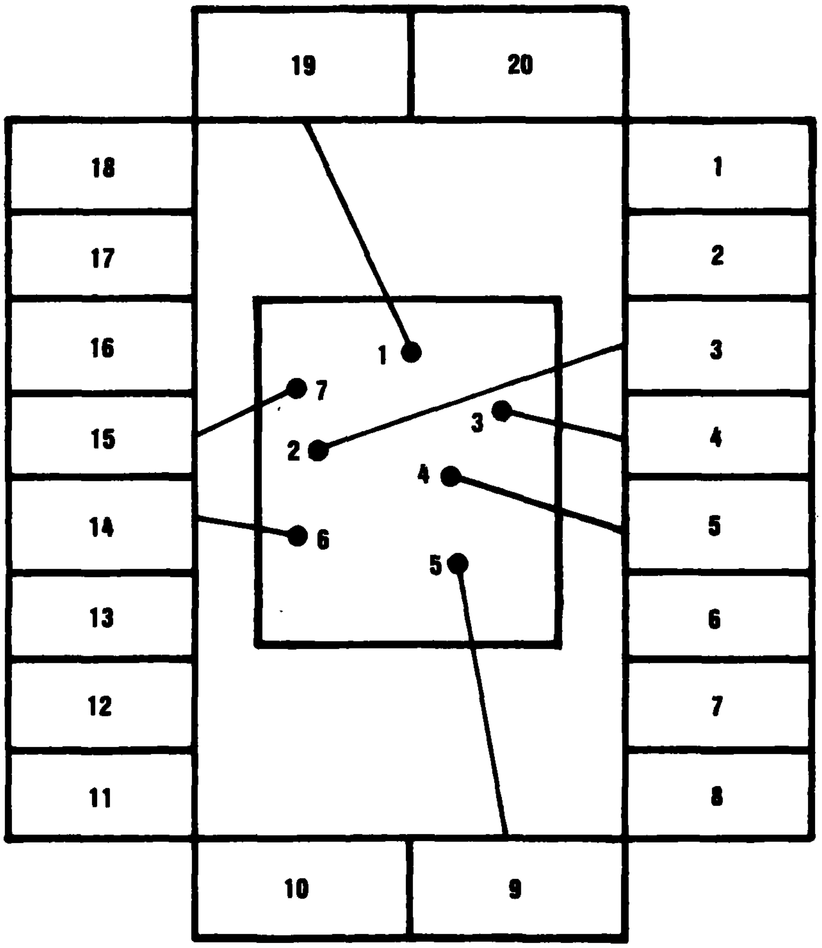


Figure 29. Solution at the end of the MTDAP procedure.

IV. Finding a MTDA

Step 0. $i = 7$, MOVE = 1, $q = 1$, OLD(1) = 0, OLD(2) = 0, $NX_0 = NX = 0$ consider $SVD_7$ in Appendix C3 and go to step 1.

Step 1. For $i = 7$, currently $t = SVD_7(15) = 1$ (point 7 is at its best assignment also with respect to objective 4); go to step 2.

Step 2. $q = 2$, $(q - OLD(2)) = 2$.

Step 2c. $i = 7$, MOVE = 1, set $i = 6$ and go to step 1.

Step 1. For $i = 6$, currently $t = SVD_6(14) = 1$, go to step 2.

Step 2. $q = 3$, $(q - OLD(2)) = 3$.

Step 2c. $i = 6$, MOVE = 1, set $i = 5$ and go to step 1.

Step 1. For $i = 5$, currently $t = SVD_5(9) = 8$ but $\bar{t} = \overline{SVD}_5(8) = 1$ and $ALT_5(1) = 0$; hence go to step 2 (as objective 3 has the priority and no alternative is available).

Step 2. $q = 4$, $(q - OLD(2)) = 4$.

Step 2c. $i = 5$, MOVE = 1, set $i = 4$ and go to step 1.

Step 1. For $i = 4$, currently $L_4 = U_4 = 5$ (no exchange is possible), go to step 2.

Step 2. $q = 5$, $(q - OLD(2)) = 5$.

Step 2c. $i = 4$, MOVE = 1, set $i = 3$ and go to step 1.

Step 1. For $i = 3$, currently $L_3 = U_3 = 4$, go to step 2.

Step 2. $q = 6$, $(q - OLD(2)) = 6$.

Step 2c. $i = 3$, MOVE = 1, set $i = 2$ and go to step 1.

Step 1. For $i = 2$, currently $t = SVD_2(3) = 11$ and $\bar{t} = \overline{SVD}_2(3) = 15$ but $ALT_2(15) = 0$; hence go to step 2.

Step 2. $o = 7$, $(q - OLD(2)) = 7$.

Step 2c. $i = 2$, MOVE = 1, set $i = 1$ and go to step 1.

Step 1. For $i = 1$, currently $t = SVD_1(19) = 4$ and $\bar{t} = \overline{SVD}_1(19) = 1$; but for $k = 1, 4$ first $\ell = 19$ (such that $\ell = SVD_1(k)$ and $\ell$ $LZ_1$) . Since $k = t$ go to step 2.

Step 2. $q = 8$, $(q - OLD(2)) = 8$.

Step 2c. $i = 1$, MOVE = 1, set $i = 0$, go to step 2b.

Step 2b. Set $i = 2$, MOVE = 2, go to step 1.

The above process will continue until $i = 7$ and MOVE = 2 without any exchange taking place at this stage (step 2a), both $OLD(1) = 7$ and $(q - OLD(2)) = 14 = 2*N$ will be satisfied to generate a branch to step 4.

Step 4. The current solution $(X_{1,19} = 1, X_{2,3} = 1, X_{3,4} = 1, X_{4,5} = 1, X_{5,9} = 1, X_{6,14} = 1, X_{7,15} = 1)$ as seen in Figure 29 is "sub-optimal" to objective 4. This phase represents the termination of the illustrative example.

### 4.3.5 Validation of Convergence of The Swinging Algorithm

In this section we discuss the optimization problem of the second objective. That is, the problem of minimizing the number of intersections between the arrows in the arrangement (MIAA). As stated earlier (Section 4.3.3), effort is made only to reduce the different distances considered in the objectives 3 and 4.

The first part of the discussion characterizes the difficulties involved in the pairwise exchange in the presence of the intersections. The last part elaborates on the rationale used in the Swinging Algorithm to tackle these difficulties.

## Pairwise Exchange and The Intersection Problem

The following definitions will help to clarify the concepts of pairwise exchange and arrow intersections.

The exchanges as performed in the heuristic always take place between a real assignment $X_{ij} = 1$ and a fictitious assignment $X_{k\ell} = 1$ (assuming $M > N$ as in Section 4.3.2; $i = 1, N$ and $k > N$). Exchanges between two real assignments are never considered as they automatically generate a non-arrangement.

Definition 4.2: A supporting line of an assignment $X_{ij} = 1$, is tne straight line passing through the internal point $i$ and a desired contact point on the boundary of the label slot $j$.

Definition 4.3: A line segment of $X_{ij} = 1$ (also referred to as arrow), is the portion of the supporting line between two points of interest.

Definition 4.4: The intersection between a pair ($X_{ij} = 1$, $X_{k\ell} = 1$; $i,k = 1, N, i \neq k; j,\ell = 1, M, j \neq \ell$) is said to be accountable in the MIAA problem, if it lies simultaneously in the line segment of $X_{ij} = 1$ and $X_{k\ell} = 1$. It is not accountable otherwise (in Figure 30a the intersection between arrow a and arrow b is accountable in the MIAA problem, whereas all the other intersections as observed are not).

Definition 4.5: An intersection is said to be $n^{th}$ accountable in the MIAA problem, if there are exactly $n$ pairs of ($X_{ij} = 1$, $X_{k\ell} = 1$) for which it is accountable simultaneously.

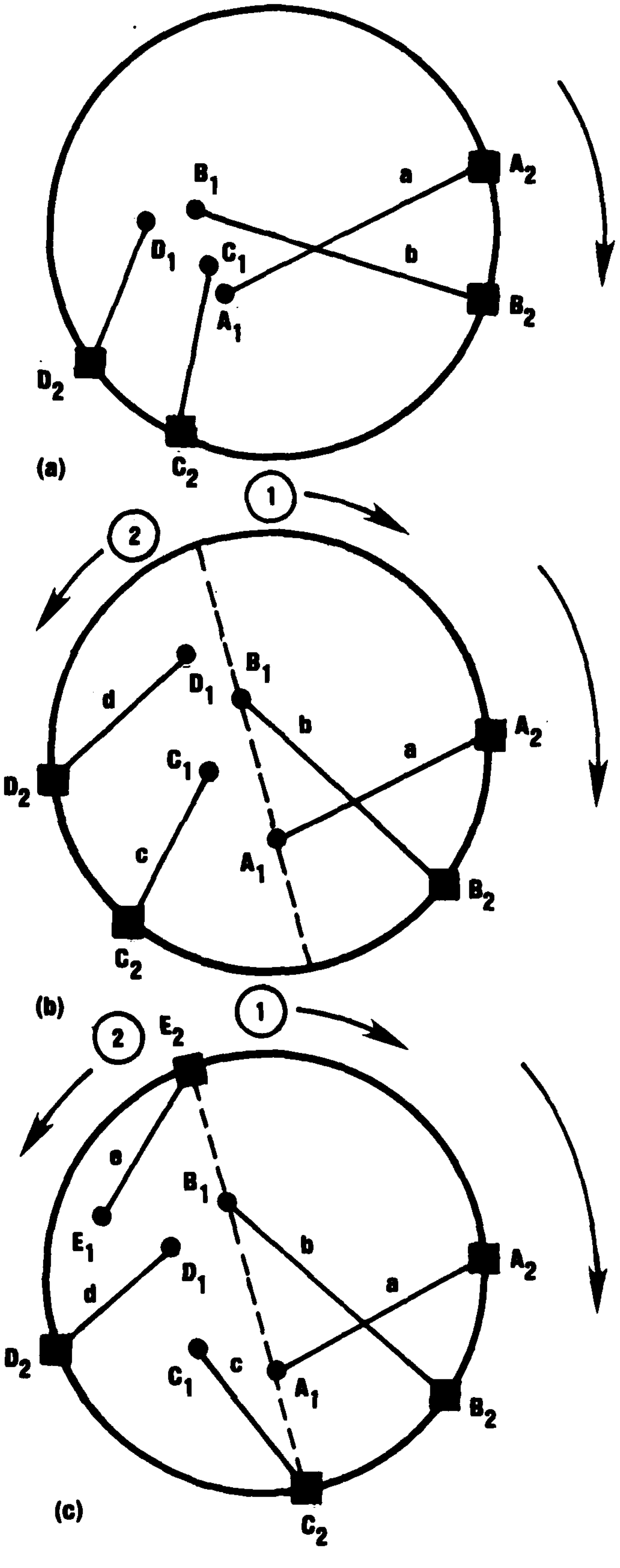


Figure 30. Some Characteristics of the Intersections.

Let I denote the point of intersection between the supporting lines of $X_{ij} = 1$, $X_{k\ell} = 1$ (assuming they are not parallel); let $(X_{ij_1}, X_{ij_2})$; $(X_{k\ell_1}, X_{k\ell_2})$ be the abscissa of the internal points and contact points on the label slot of $X_{ij} = 1$, $X_{k\ell} = 1$ respectively. Let $X_I$ be the abscissa of the point I. The following theorem characterizes the accountability of I.

Theorem 4.1: I is accountable in the MIAA problem if, and only if, there exist a pair $(\lambda_1, \lambda_2)$ satisfying the following conditions:

$$\lambda_1 X_{ij_1} + (1-\lambda_1)\, X_{ij_2} = X_I$$

$$\lambda_2 X_{k\ell_1} + (1-\lambda_2)\, X_{k\ell_2} = X_I \qquad (10)$$

and $\lambda_1, \lambda_2 \in [0,1]$.

Proof: The proof follows from the convexity property of $X_{ij} = 1$, $X_{k\ell} = 1$ and $X_I$ .

Corollary 4.2: I is $n^{th}$ accountable if n such pairs of $\lambda$'s and $(X_{ij}, X_{k\ell})$ can be found to satisfy independently the conditions in (10).

The above Theorem 4.1 and Corollary 4.2 establish the essential ingredient to systematically identify every accountable intersection in the layout.

Given an accountable intersection of any two line segments of assignments, it is essential to investigate the properties of the different regions in the page. For instance, it can be seen in Figure 30b, that the straight line passing through points $A_1$ and $B_1$ divides the page into two regions 1 and 2. Also to preserve the desired order in the layout (i.e., clockwise), arrow a must always begin in the region delimited by the points $B_2$ and $D_2$ (when $B_2$, $D_2$ are fixed); also arrow b must begin in the region delimited by the points $A_2$ and $C_2$ (when $A_2$, $C_2$ are fixed). The next proposition characterizes the region of non-accountable intersection between arrow a and arrow b (Figure 30b) in their limit zones.

Proposition 4.3. The intersection between arrow a and arrow b is always accountable in their limit zones except if either one (but not both) begins within region 2.

Proof. The proof is omitted here but can be established by geometrical construction.

Corollary 4.4: Given a page and a set of internal points, a region 2 can be found for any pair of arrows where the intersection (if any) of the pair is always non-accountable.

When attempting to solve the MIAA problem using any pairwise (or similar) exchange method, it is required, as pointed out above, to always make at least one label slot available and accessible in the region 2 for the pair of arrows in accountable intersection that is considered. However, several difficulties are encountered in the operations of creating and accessing a desired region 2 during an exchange process. In addition it may not always be possible to create such a region 2 for every pair.

Definition 4.6: During the pairwise exchange process if one pair of arrows works systematically[7] to make every part of region 2 of another pair of arrows (in accountable intersection) inaccessible at all times, a 'Lock' is formed, if either of the arrows is considered for exchange.

Example: Lock is formed if an arrow (say c) and any other arrow (say e), both begin in region 1, or at the limits of region 2, provided arrow a or arrow b is considered for an exchange. Figure 30c illustrates a lock when both arrows (c and e) begin exactly at the limits of region 2.

Definition 4.7: During the pairwise exchange process, an arrow having no accountable intersection must necessarily be forced to perform an exchange which will worsen its current intersection status, in order to open a region 2 for other pair(s) or arrows constitutes a 'Bridge'.

An example of a Bridge is seen in Figure 31 in which assignment $X_{5,13}$ can not improve in its current feasible limit zone $LZ_5 = 8,9...,16$ , unless that zone is further open beyond its lower limit $L_5 = 8$ . To create such an opening the intersection status of $X_{4,6}$ must necessarily be worsened. In this instance $X_{4,6} = 1$ is said to form a Bridge over any further reduction of accountable intersections.

[7] Note: "Systematically" means, either one (or both) of the arrows is in a position to prevent the exchange which would result in the decrease of intersections.

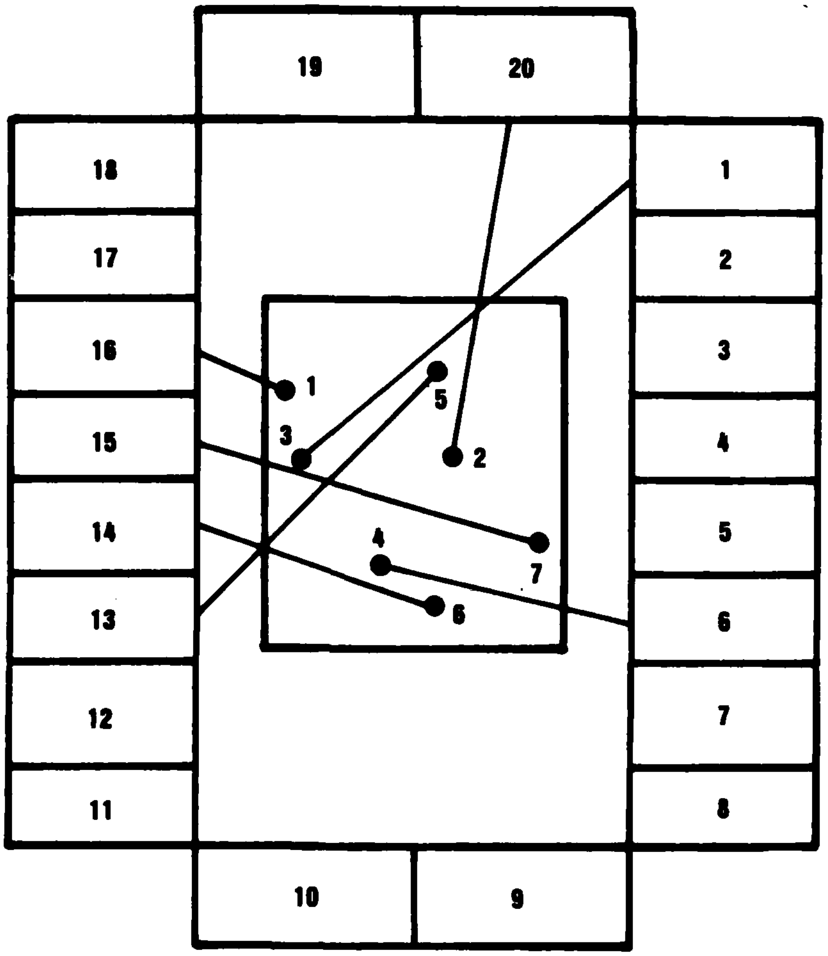


Figure 31. Example of a Bridge.

Notice that $X_{46}$ = 1 cannot perform any further exchange without getting worse in number of accountable interactions.

## Rationale Used in The Swinging Algorithm

Definition 4.8: An improving exchange is one in which the total number of accountable intersections is reduced.

Definition 4.9: A stationary exchange is one in which the total number of accountable intersections remain the same.

Definition 4.10: A 'Window' is the set of label slots ($\ell$) in the limit zone of an assignment $X_{ij} = 1$ (involved in at least one accountable intersection), for which the exchange of $X_{ij} = 1$ and $X_{k\ell} = 1$ (fictitious) results in non-accountable intersection on $X_{i\ell} = 1$ (see Figure 30c).

The Swinging Algorithm uses improving and stationary exchanges which are performed iteratively during backward (MOVE = 1) and forward (MOVE = 2) processes. The algorithm always seeks for a steady, but not a speedy decrease in the objective function.

Speedy decrease always aims at finding and performing the most improving exchange (if any) for the assignment that is currently considered. This type of decrease which always attempts for exchanges in windows, increases very quickly the type of bridge situation as seen in Figure 31. Speedy decreases are avoided in the algorithm with the mechanisms used in step 2 and step 6 (part II).

The selection rule for exchange used in the algorithm creates a maximum opening of the limit zone for the arrow which is being considered for exchange. Next, it insures that the possible minimum accountable intersection on that arrow (possibly zero) be selected only if it is the first available; at the limit of the new zone; otherwise the first available slot with the same number of intersections is selected and a stationary exchange is performed.

Step 6 ensures that the best slot is selected at a later stage by steadily relaxing the selection rule of step 2 to allow for an improving exchange in the Window. This type of exchange is a progressive Window exploration.

A speedy and non-careful decrease of the objective function also augments the possibility of the occurrence of the Lock. However, to control the occurrence of a Lock is a difficult process, as it involves the careful monitoring of every pair of assignments with respect to every other assignment during the iteration process. This will insure that region 2 of every assignment remain ultimately open for the appropriate exchange.

In the algorithm only one type of check is performed towards the prevention of a Lock. This prevention is performed in step 1 and step 5. During every iteration step 5 updates the status of every assignment, when it is performing an exchange. Step 1 uses this information to prevent any exchange which will result exactly in the same assignment of the previous iteration. Truly, these mechanisms can only guarantee the prevention of the type of Lock of the region of improvement of an arrow by its immediate neighboring arrows. There is no other systematic way to prevent the formation of Lock and guarantee the convergence to a global solution of the MIAA problem for every kind of random distribution of the internal points in the picture, using pairwise exchange method similar to that of the Swinging Algorithm.

In reality only an exact solution procedure (i.e., Branch and Bound anc other integer programming methods) which systematically examine every feasible arrangement may guarantee convergence. This problem and its related issues are discussed later in the current section.

## Computational Results

The Swinging Algorithm is coded in FORTRAN IV, compiled and run on a CDC CYBER 174 Computer System. The compilation time for the program was 7.6 CPU seconds, and its storage requirement is about 32.5K. The program includes all parts (i.e. FAA, MIAA, MTDAP, MTDA) of the simple page layout problem. The program and output listing of the illustrative example (Figure 24) are available in Sylla and Babu (1982).

The time to solve the illustrative example is .946 CPU seconds which is distributed between the four parts as follows: FAA, .47; MIAA, .328, MTDAP, .108, MTDA, .04.

Special interest is given to the MIAA problem and several methods were attempted to further reduce both the objective function value and the computer execution time.

An improvement method developed provides the best starting arrangement (from the FAA) to begin the MIAA procedure. That is, given that the first internal point can be assigned to any one of the label slots (see assumption 2), one way of improvement is to find a scheme to quickly solve the FAA problem starting from any point considered as the first in the arrangement; then choose to swing for (MIAA) from the arrangement having the minimum possible number of intersections (NX). This method is based on the assumption that the number of intersections obtained from the FAA using different points as the starting point are different. Table 6 shows the results of the FAA starting with every one of the 7 points of the illustrative example (Figure 24). These results show the NX's obtained at the end of the FAA procedure and the final solution of the MIAA. The table also shows the computer execution time, and the total number of swings and exchanges performed.

Table 6 also reflects the searching of the solution with the minimum possible number of NX to use for the solution of the MIAA problem. This will result in an improvement as it can save many swings (i.e., starting from point 3 or 5). This saving is total if there exists a point among the set of points for which the application of the FAA procedure will generate an arrangement with NX = 0. However, starting from the best arrangement can also result in a lock type situation and a sub-optimal solution at the end of the MIAA procedure (i.e., case of point 2, 4 and 7).

To further test the algorithm for Locks, a single page picture like Figure 24 with 16 label slots was considered. Twenty-five (25) problems were randomly generated (by a random generation of a problem we mean randomly generating 7 uniform points in the picture and randomly numbering these points from 1 to 7). Two methods as defined below were used to solve these problems to further analyze and compare the occurrence of a Lock.

- Method A: regular FAA procedure followed by regular MIAA procedure
- Method B: modified FAA[9] procedure followed by regular MIAA procedure.

[9] The modified FAA procedure searches for the best arrangement among N possible arrangements without completely generating all of them (N=7).

Table 6. Results Obtained from Starting at Different Points in Figure 24.

| Procedure | | Starting Point | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| FAA | a | 10 | 3 | 1 | 1 | 1 | 1 | 1 |
| | b | .47 | .47 | .47 | .47 | .47 | .49 | .47 |
| MIAA | a | 0 | 2 | 0 | 1 | 0 | 0 | 1 |
| | b | .328 | .39 | .043 | .347 | .072 | .072 | .674 |
| | c | 3 | 7 | 1 | 7 | 1 | 1 | 18 |
| | d | 10 | 9 | 1 | 9 | 3 | 2 | 15 |

a = Number of intersections (NX)

b = CPU seconds

c = Total number of swings performed

d = total number of exchanges performed

The results obtained in terms of the number of intersections (NX) are seen in Figure 32. The results as expected revealed that the Method B always starts with an arrangement better or as good as the starting arrangement of Method A. It can be seen that Method B does better than or as good as Method A up to 84% of the time (based on the sample experiments). Clearly, the improvements achieved by both of these methods, as evidenced appear to be obstructed by a Lock situation causing premature termination. The computer execution times in Figure 33 and Figure 34 indicate that the Method B takes slightly more time than Method A (an average of .054 CPU second during the FAA procedures which increases to .20 cpu second during the MIAA). The total time taken by Method B is still very reasonable to justify the addition of a scheme which improves the number of intersections in its final arrangement.

This improvement is conceived to work in the following manner (Method C):

1. Store during the iterations of Method B, all essential information of the last k arrangements (i.e., $X_{ij(s)}$, sequence of swings last performed) obtained from the previous improving exchanges.
2. At the end of Method B file the result at hand. Consider the k arrangements as stored starting from the most recently stored one; update all results needed for the MIAA procedure.
3. Perform the MIAA procedure on that arrangement using the reverse sequence of the sequence last performed (as stored).
4. Terminate when all k arrangements are considered or the maximum number of swings allowed is exceeded. At termination, select the best arrangement and report. The conceptual diagram for Method C is given in Figure 35 .

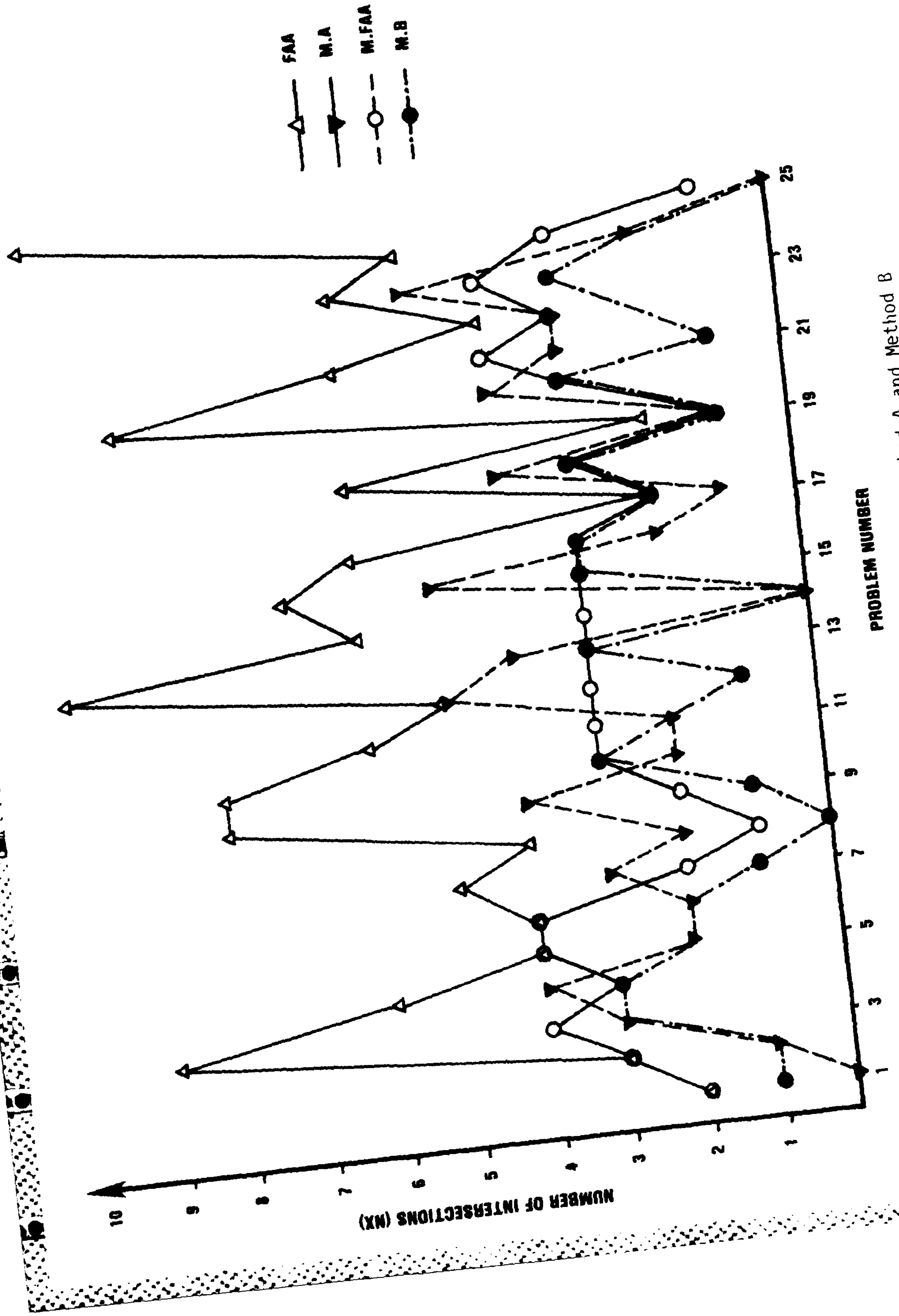


Figure 32. Solutions reached by Method A and Method B

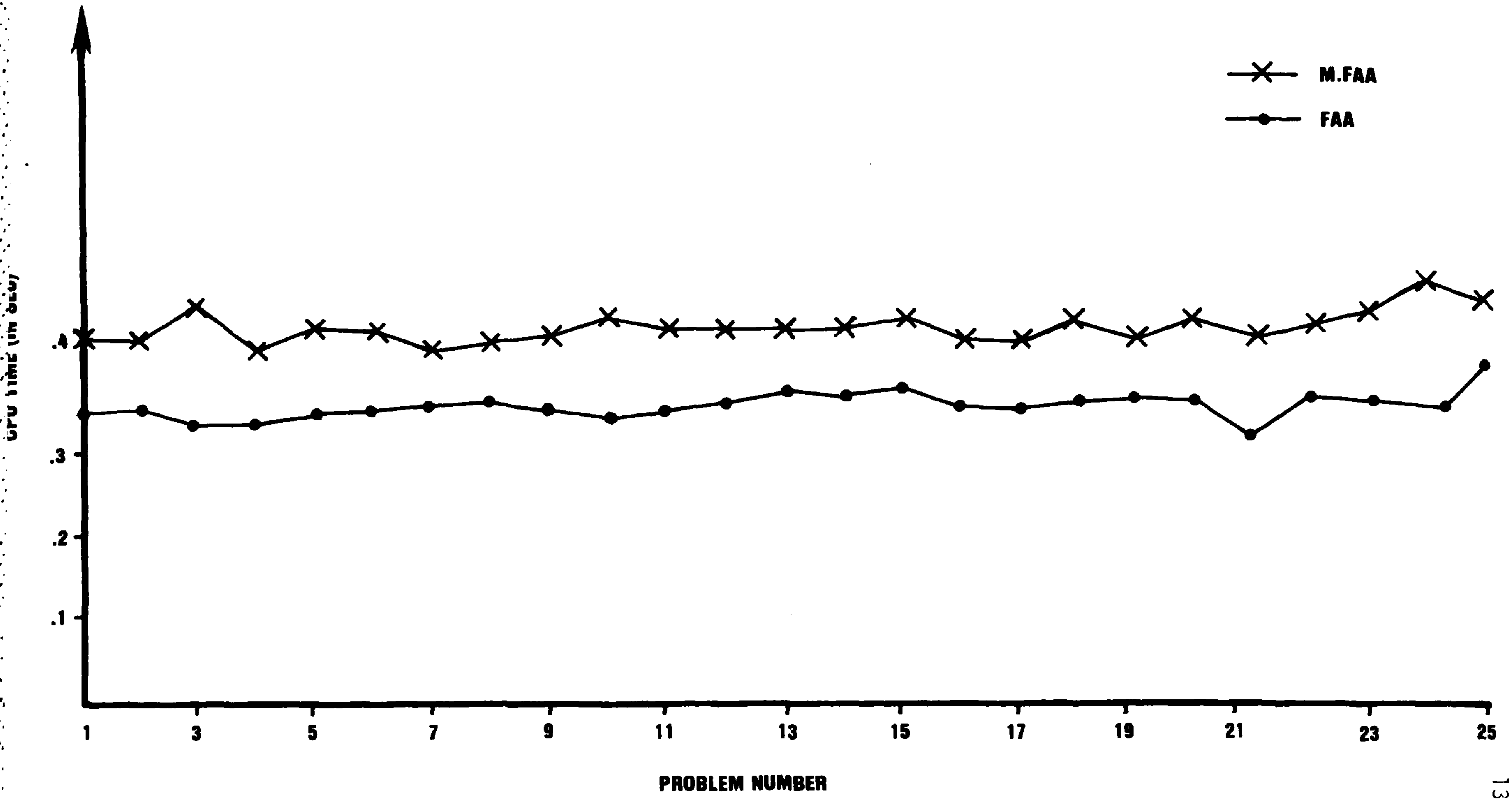
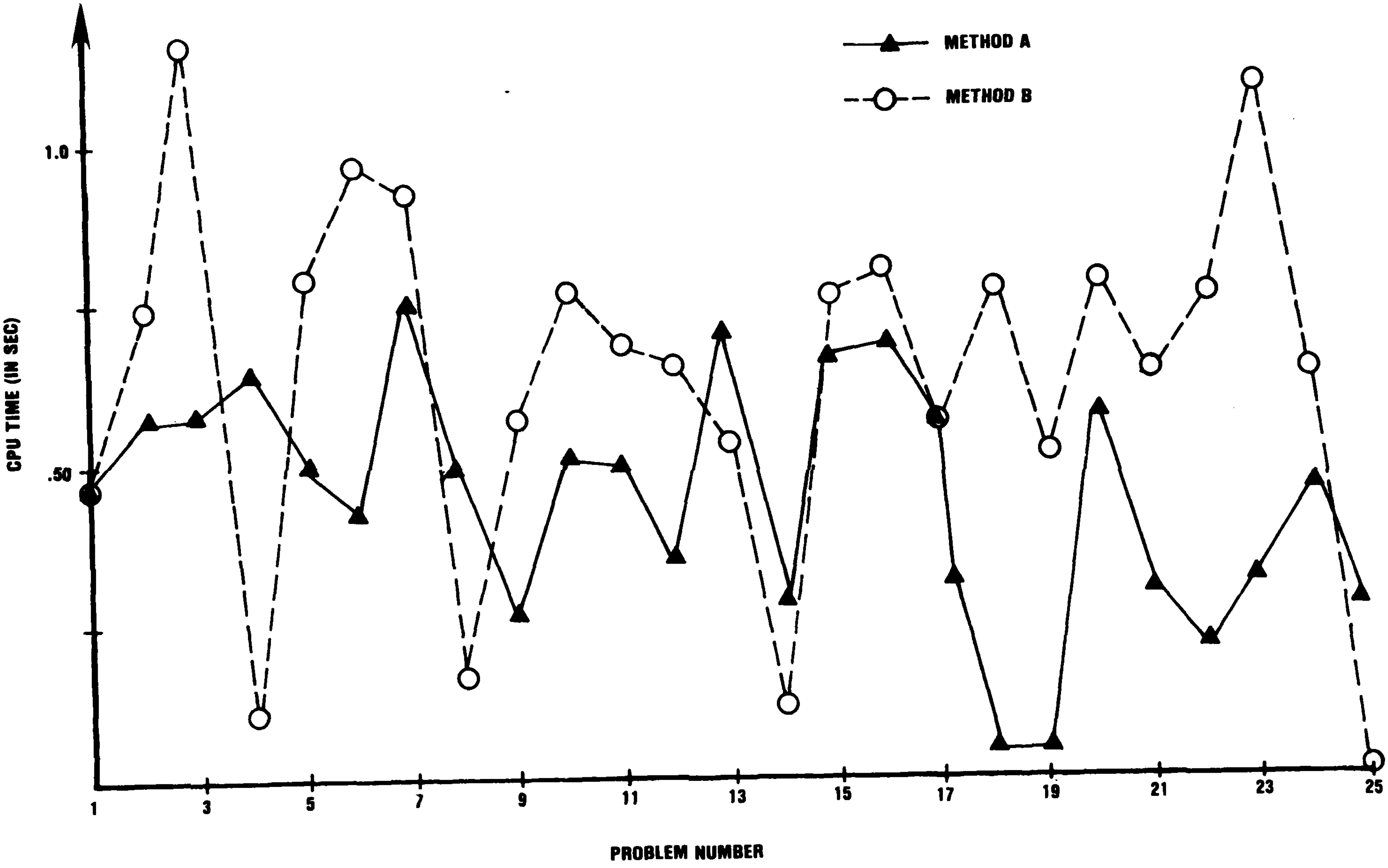


Figure 33. Times of FAA and M.FAA



F ,ure 34. Times of Method A and Method B

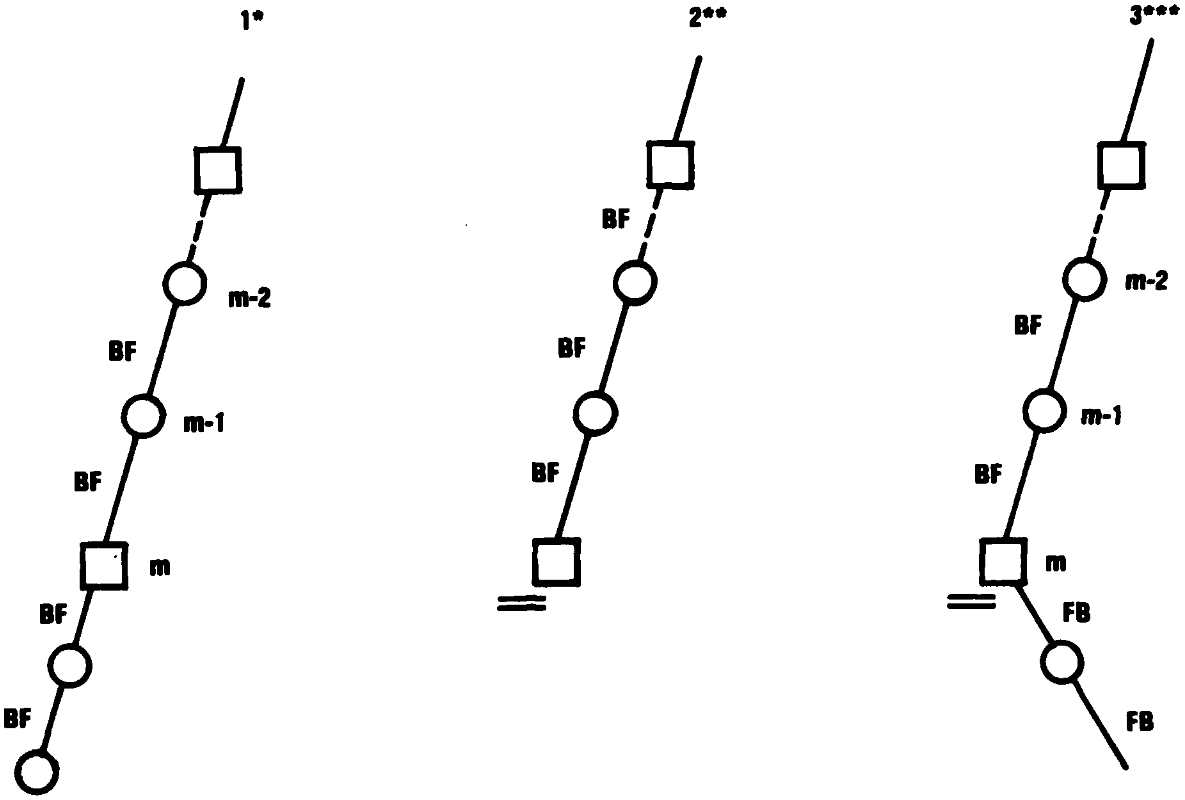


Figure 35. Conceptual diagram of Method C (K=1)

* 1 Keep storing the arrangement from the last improving exchange.

** 2 If all stopping criteria are satisfied and NX≠0, backtrack to arrangement m; perform the swing using FB (or reverse) swing as seen below.

*** 3 If an improvement is found, update the arrangement in storage area; go to repeat from 1.

The same example problems were solved using Method C for k = 1 and k = 2. The run with Method C starting with modified FAA, produced improved results for problems #1,2,17 and 20 when k = 1 . For k = 2 additional improved results were obtained for problem #3, 10 and 23. Figure 36 shows the plots of the results from Method C (k = 1 and k = 2) against the results from Method B. The corresponding times of execution are shown in Figure 37. Table 7 gives the results of selected problems used in the sample experiment. It can be seen that for all results obtained with Method A, better or equal results (in terms of NX) are obtained from Method C (k = 2) except for problem #16 (observe NX = 2 for Method A while NX = 3 elsewhere). This can be explained from the difference of the starting conditions of Method A and others (B and its improved version C). The modified FAA used in these methods has directed the exchange process into an early Lock and a premature termination.

Maximum limits are imposed on the number of iterations (swings) and exchanges during the runs with Method C in addition to the stopping criteria described in the algorithm.

The interpretation of the number of iterations and exchanges for Method C as seen in the table, may be found inaccurate until one analyzes effectively as to how they take place during the process at the end of Method B (step 2). Such analysis goes beyond the scope of this dissertation.

The method recommended as the result of this experiment is the Method B or its improvement (Method C) with k not exceeding 2. However, this must be done only when assumption 2 holds good and precaution must be taken for the stopping parameters.

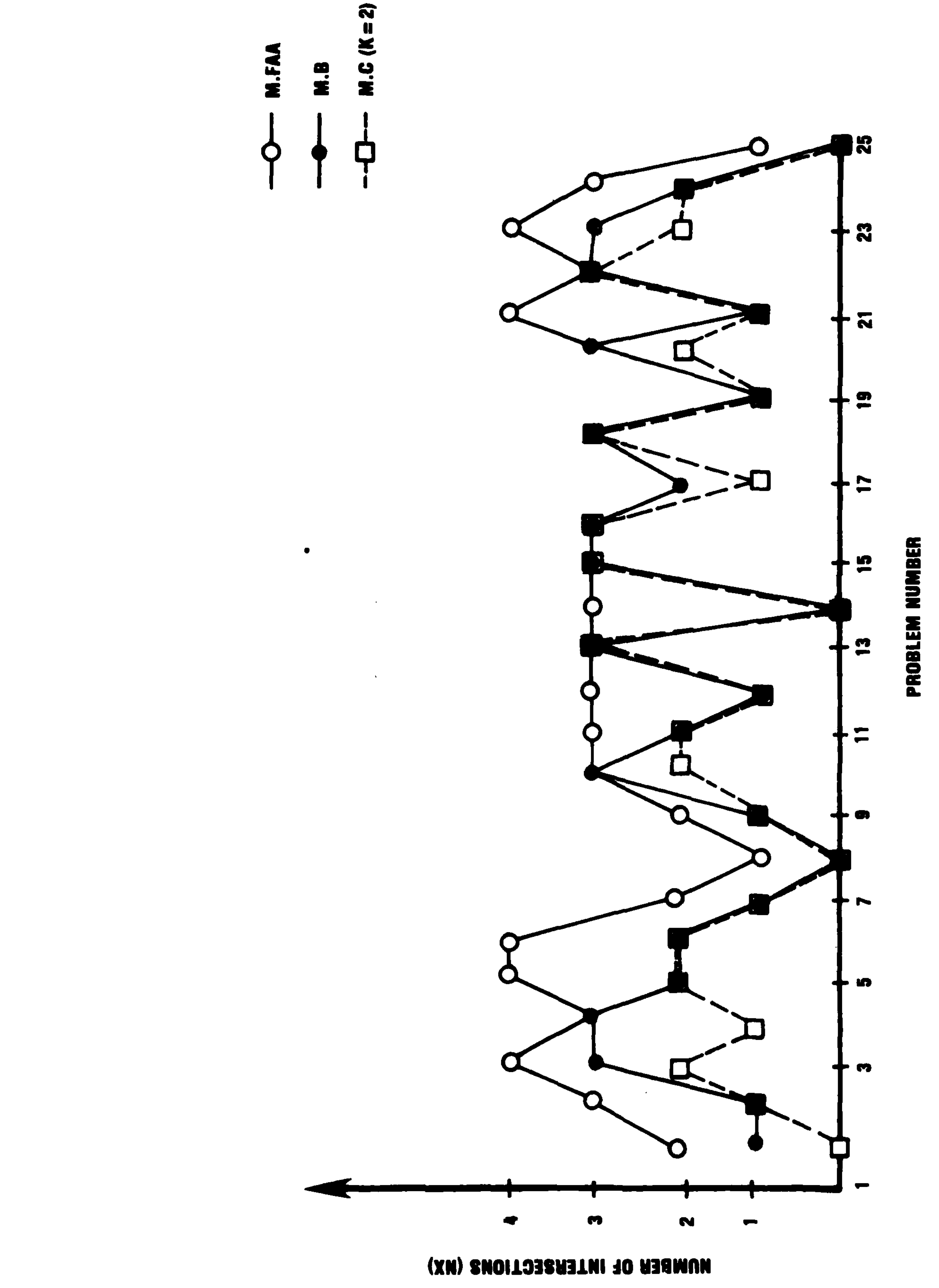


Figure 36. Solutions reached by M.B and M.C (starting from M.FAA)

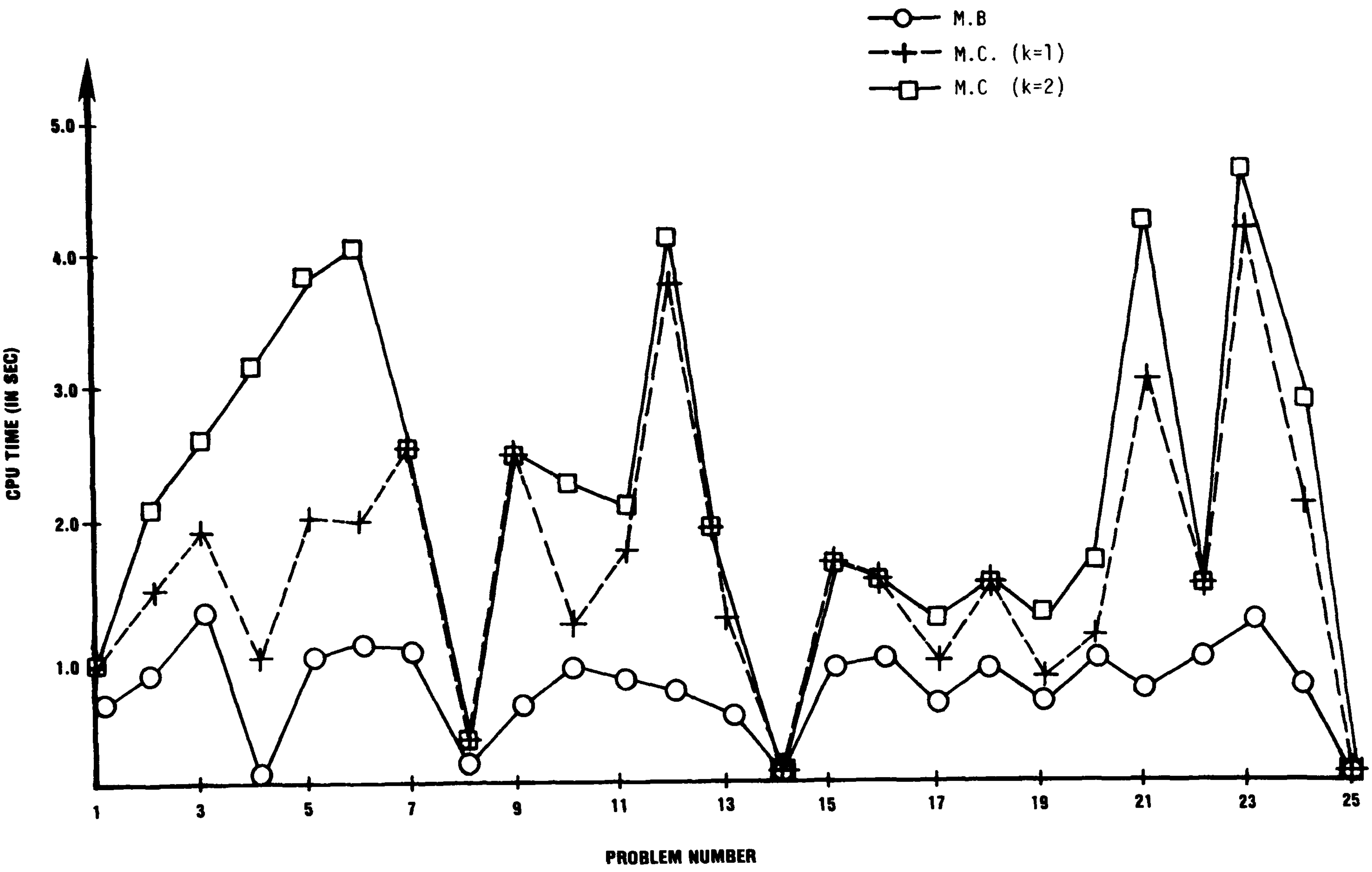


Figure 37. Times of Method B and Method C (k=1,2)

Table 7. Results of Different Methods for Selected Problems

| Problem A | Method A | | | Method B | | | | Method C<br>k = 1 | | | | Method C<br>k = 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0 | 8 | 2 | 1 | 8 | 18 | 2 | 0 | 13 | 26 | 2 | 0 | 13 | 26 |
| 3 | 9 | 3 | 10 | 4 | 3 | 11 | 55 | 4 | 3 | 18 | 67 | 4 | 2 | 30 | 79 |
| 4 | 6 | 4 | 19 | 3 | 3 | 4 | 3 | 3 | 1 | 13 | 27 | 3 | 1 | 13 | 27 |
| 10 | 8 | 2 | 10 | 3 | 3 | 9 | 28 | 3 | 3 | 11 | 48 | 3 | 2 | 27 | 69 |
| 16 | 6 | 2 | 14 | 3 | 3 | 14 | 28 | 3 | 3 | 13 | 52 | 3 | 3 | 13 | 52 |
| 17 | 2 | 1 | 2 | 2 | 2 | 8 | 23 | 2 | 1 | 10 | 29 | 2 | 1 | 14 | 35 |
| 20 | 9 | 4 | 13 | 3 | 3 | 10 | 36 | 3 | 2 | 12 | 41 | 3 | 2 | 17 | 49 |
| 23 | 6 | 5 | | 4 | 3 | 15 | 43 | 4 | 3 | 42 | 100 | 4 | 2 | 45 | 126 |

The numbers in each column are (left to right):

- Beginning NX
- Ending NX
- Number of swings performed
- Number of exchanges performed

Max # of swings allowed = 100

Max # of exchanges allowed - 120

### 4.3.6 Other QAP Algorithms Versus The Swinging Algorithm

None of the current existing methods to solve the usual QAPs (Section 2.1) conform to the (AAP) as discussed earlier. Serious modifications of the methods using pairwise exchange are needed before they can be applicable to solve any one problem which fit the QAP structure (i.e., MIAA, MTDAP, MTDA). One such modification must be made to avoid exchanges which will result in a non-arrangement. Another modification is needed to reduce the computer storage requirement. For instance in the illustrative example (see Figure 24), $N = 7$, $M = 16$, the usual pairwise exchange algorithms (see Buffa *et. al.* (1964), Vollman *et. al.* (1968), Heider (1972), Los (1978), .., etc.) have a matrix to store the cost of interaction between every pair of arrows (real and fictitious) in the arrangement. In the problem at hand three such cost matrices are needed, especially when solving the MTDA problem (4th objective); the size of each matrix is M X M elements, each of which must be updated at every exchange of the procedure. Each updating operation requires as much as $(\frac{M(M-1)N!}{(N-2)!2!})$ operations. This amounts to 2,040 operations for each matrix, unless special scheme is used. This value still increases if higher order exchange is used (i.e., 117600 for the 3 x 3 exchange).

Exact solution type methods such as Integer Programming (see Bazaraa and Sherali (1978)) and Branch-and-Bound may be ideal as they guarantee the global optimal arrangement at all times. However, they are very time consuming schemes and are found impractical even for problems of practical sizes. To solve a problem of similar size ($M = 20$) without consideration of arrangement, Bazaraa and Sherali (1978) reported to have taken 902.4 CPU seconds on a CYBER 74. There is no method using Branch-and-Bound technique to date which is reported to solve this size problem in less than 250 seconds (see Mirchandani and Obata (1979). In addition these methods must all be modified to include the consideration of the arrangements between assignments.

## 4.4 Summary

The page layout problem presents two major categories which are the simple page and complex page layout. This chapter has presented the rationale for this categorization. The formulations of the simple page layout problem (AAP) is discussed in detail. The problem as seen is a modified quadratic assignment problem with multiple objectives. An algorithm called the 'Swinging Algorithm' based on the general pairwise exchange technique is developed and implemented on an example problem. Two improvements of the algorithm are also developed and a computational experiment with 25 randomly generated pages is reported. Due to the nature of the (AAP) at hand no numerical comparison is possible. The next chapter will examine the generalization of the Swinging Algorithm to the layout pages having more than one picture.

# CHAPTER V

# GENERAL PAGE LAYOUT

Chapter IV describes the details of the modelling problem of a page containing two pictures where one is the overview. At this stage only one type of picture-to-picture relationship is considered. This simplicity allows us to write a mathematical model omitting almost entirely the human and machine interface consideration. In the present chapter, the problem of more than one picture on a page will be considered. In addition other layout problems of the subprocedure, after splitting as in Chapter III, will be examined.

## 5.1 Complex Page Layout Problem

Unlike the simple page layout, the general page layout problem fits all the description of section 1.3. Up to four pictures are allowed in the page and more than one picture-to-picture relationship is allowed.

### Assumptions

(1) All assumptions made in Chapter III for the design of the procedure splitting model (see Appendix B) are also assumed.

(2) Assumptions (4) and (5) made in the Simple Page Layout Model are also assumed.

(3) A page is assumed to have at least one picture and one label. Every such minimal set is assumed to physically fit in the available layout space allowed in a page (recall rule 1 in section 3.2).

### Model of Complex Page Layout

The description of the complex page layout problem includes the description of the simple page layout and added constraints. These added constraints forbid two types of line intersections in a page. One such type of intersection is the intersection of any line segment of an assignment with any boundary of a picture if the internal point of the assignment is not located within that picture. The other type of intersection forbidden is the intersection of any line segment of an assignment with any boundary of the selected label slot if the internal point of the assignment is not assigned to that label slot.

These constraints when added to the layout problem transform the original (AAP) into a Modified Assignment Arrangement Problem (MAAP), which can be stated as follows:

A. Minimize:

The multi-criteria objective of the (AAP)

B. In such a way that:

1. All constraints of the (AAP) are satisfied.
2. All added constraints are satisfied.

One method of design of the complex page is to consider the page as a continuous space and to consider the internal point to be a random point which may lie anywhere in the page; a page can be assumed to be a random rectangle around a non-empty set of these points. The dimensions and the orientation of each picture are known, but no particular order or orientation exist between its internal elements.

The solution to the problem therefore enters the pictures in the page in such a way as to create enough space in the page around and between the pictures to permit a maximal number of label slots to be drawn. The internal points are then assigned to the label slots in such a way as to optimize and satisfy all desired objectives and constraints in the (MAAP). The solution procedure is therefore a two-phase process which includes:

Part a: A procedure to best enter the elements in the page,

Part b: A procedure to solve the MAAP.

Part b is handled through a modification of the Swinging Algorithm; it is discussed in a later section. Part a includes the aspects of man-machine interface. These aspects include the alternative choices usually considered by the human designers. These alternatives and their related problems are investigated using a questionnaire. A selection scheme is derived to give the alternative which best enters the elements in the page.

## 5.2 The Questionnaire Design

This questionnaire was designed to look more closely into the decision alternatives within a page. It was aimed at helping the computer solution technique to mimic as closely as possible the layouts which the intelligent human would design.

The questionnaire was submitted to 14 persons knowledgeable in producing procedure training manuals. The questionnaire examined 15 types of questions and offered 2, 3 or 4 alternative responses for each question. The details of these questions and alternative responses are seen in Appendix D1. This appendix also includes the details about the participants, and the methodology involved.

The questions were designed and numbered in order of increasing difficulty. The first questions generally investigated specific elements of the page layout process, while the later questions examined global aspects of the elements in a page. Therefore the nature of the later questions required a greater depth of analysis from the participants, some of which was prompted by answering the earlier questions. The ultimate desire for a good analysis and interpretation of the responses and the difficulty mentioned above recommended a division of the questions into four subgroups with each group concerned with one or more aspects of the page layout. This decomposition is illustrated in Table 8. Participants were also offered a space to comment about their responses.

## Analysis of the Responses from the Questionnaire

The ranking of the alternative choices of the different questions as received from the participants can be seen in Table 9. In order to conduct a meaningful analysis of these responses and to arrive at a meaningful conclusion, a reorganization of these data is essential. One way to do this is to consider the ranking of the alternatives involved in each question and to assign a value of 1 to the best alternative, the value of 2 to the next best alternative, etc. This type of assignment can be used for each question (columns of Table 9), with the exception of questions 8 and 10 which are discussed along with the subjects' comments. As a next step, an appropriate statistical analysis can be used to examine the difference and similarities between the alternatives.

Reorganizing the data this way for questions (1-7) and (9, 11-13c) gives Table 10. In this table we have for each question $k = 3 - 4$ alternatives (i.e., A, B, C and D) in the column and $N = 11 - 14$ subjects responses transformed in 1, 2, 3 and 4 rank values. The layout under each question can be identified as a two-way classification with one observation per cell. The appropriate statistical tests to be used for each question are:

- Test 1: The Friedman two-way analysis of variance by ranks in the first place for testing whether all 3 (or 4) alternatives differ among each other as a group.

| Question | 1<br>About order when reading labels (No consideration of space limitations) | 2<br>About order between labels with consideration of space limitation | 3<br>About space limitation and duplication, sizes of pictures, of labels of arrows | 4<br>About general layout and overview |
|---|---|---|---|---|
| 1 | Group 1 | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | Group 2 | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | Group 3 | |
| 11 | | | | |
| 12 | | | | |
| 13a | | | | Group 4 |
| 13b | | | | |
| 13c | | | | |

Table 8. Subdivisions of the questionnaire

TABLE 9. Ranking of Alternatives as Received from Participants (Subjects). For Each Question Whose Letters (i.e., A,B,C,...,etc.) Read the Subject Best Alternatives on the Left and Worst Alternatives on the Right.

| Question / Subject | 1 | | | | 2 | | | 3 | | | 4 | | | | 5 | | | | 6 | | | | 7 | | | | 8 | | | | | | 9 | | | | 10 | | 11 | | | 12 | | | 13a | | | | 13b | | | | 13c | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | D | C | A | B | A | B | C | A | B | C | A | B | C | D | B | C | A | D | E | F | G | H | I | J | L | K | B | C | I | J | E | F | B | C | D | A | X | | A | B | C | C | B | A | B | A | D | C | C | D | A | B | A | C | B | D |
| 2 | A | C | B | D | A | B | C | A | B | C | B | A | D | C | B | C | D | A | F | E | G | H | I | J | K | L | B | I | E | C | I | D | B | | | | | | C | B | A | A | B | C | A | B | D | C | B | D | A | C | A | B | C | D |
| 3 | A | D | B | C | A | B | C | A | B | C | A | B | D | C | B | D | C | A | E | G | F | H | I | J | K | L | B | D | E | G | I | J | B | D | A | C | | X | C | B | A | A | B | C | A | B | C | D | A | B | C | D | B | A | D | C |
| 4 | A | C | B | D | A | C | B | A | C | B | B | A | D | C | B | C | D | A | G | E | F | H | I | J | K | L | B | C | E | G | I | J | B | | | | | X | C | B | A | A | B | C | B | D | A | C | A | C | B | D | A | B | C | D |
| 5 | A | D | C | B | A | C | B | A | B | C | A | B | CD | CD | B | D | C | A | G | E | F | H | I | J | K | L | | | | | | | C | A | B | D | | X | C | B | A | | | | A | D | B | C | A | B | C | D | A | D | B | C |
| 6 | A | C | D | B | A | C | B | A | C | B | A | B | D | C | B | C | A | D | F | E | G | H | I | K | J | L | B | C | F | E | I | K | B | C | D | A | | X | C | B | A | A | B | C | A | C | B | D | A | B | D | C | A | B | C | D |
| 7 | B | A | C | D | A | B | C | A | B | C | A | B | C | D | B | C | D | A | E | G | F | H | I | J | L | K | C | B | E | F | I | J | C | B | A | D | | X | B | A | C | A | C | B | A | D | C | B | A | B | C | D | A | B | D | C |
| 8 | A | C | B | D | A | B | C | A | B | C | D | A | B | C | B | C | D | A | E | F | G | H | I | JKL | JKL | JKL | B | C | F | G | I | J | D | C | AB | AB | | X | C | B | A | | | | A | BD | BD | C | A | C | B | D | A | BCD | BCD | BCD |
| 9 | A | B | C | D | A | BC | BC | A | BC | BC | B | A | D | C | B | D | C | A | F | E | H | G | I | L | JK | JK | B | C | D | I | F | L | C | D | B | A | | X | B | C | A | A | C | B | A | A | CD | CD | A | B | CD | CD | A | B | CD | CD |
| 10 | A | B | C | D | A | B | C | A | B | C | A | B | D | C | B | D | C | A | G | E | F | H | | | | | B | C | D | E | I | J | C | B | A | D | | X | B | A | C | | | | A | B | C | D | A | B | C | D | A | B | C | D |
| 11 | A | C | D | B | A | C | B | A | C | B | A | B | D | C | B | D | C | A | E | F | G | H | I | L | J | K | B | D | E | F | I | L | B | C | D | A | | X | A | C | B | A | C | B | A | C | B | D | A | D | B | C | A | B | C | D |
| 12 | D | B | A | C | A | B | C | A | B | C | B | A | C | D | C | E | D | A | F | E | G | H | J | I | K | L | C | B | F | E | J | I | C | A | B | D | | X | A | B | C | C | A | B | A | D | B | C | C | A | B | D | A | C | B | D |
| 13 | B | A | D | C | A | B | C | A | B | C | A | B | D | C | A | D | C | B | E | G | H | F | I | J | K | L | A | D | E | G | I | J | D | C | B | A | | X | B | | | C | B | A | D | C | B | A | B | C | D | A | A | | | |
| 14 | A | C | B | D | A | B | C | A | B | C | A | B | C | D | B | D | C | A | G | E | F | H | K | L | I | J | B | D | G | E | K | L | D | B | C | A | | X | A | B | C | A | B | C | A | B | D | C | A | B | C | D | A | B | C | D |

TABLE 10. Ranks and Friedman's Test Results of the Subject Response of the Alternatives in the Different Questions

| Question | 1 | | | | 2 | | | 3 | | | 4 | | | | 5 | | | | 6 | | | | 7 | | | | 9 | | | | 11 | | | 12 | | | 13a | | | | 13b | | | | 13c | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | A | B | C | D | A | B | C | A | B | C | A | B | C | D | A | B | C | D | E | F | G | H | I | J | K | L | A | B | C | D | A | B | C | A | B | C | A | B | C | D | A | B | C | D | A | B | C | D |
| 1 | 1 | 4 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 3 | 1 | 2 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 4 | 3 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 2 | 1 | 2 | 1 | 4 | 3 | 3 | 4 | 1 | 2 | 1 | 3 | 2 | 4 |
| 2 | 1 | 1 | 2 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 2 | 1 | 4 | 3 | 4 | 1 | 2 | 3 | 2 | 1 | 3 | 4 | 1 | 2 | 3 | 4 | | | | | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 4 | 2 | 1 | 3 | 2 | 4 | 1 | 2 | 3 | 4 |
| 3 | 1 | 1 | 4 | 2 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 4 | 3 | 4 | 1 | 3 | 2 | 1 | 3 | 2 | 4 | 1 | 2 | 3 | 4 | 3 | 1 | 4 | 2 | 3 | 2 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 2 | 1 | 3 | 4 |
| 4 | 1 | 3 | 2 | 4 | 1 | 3 | 2 | 1 | 3 | 2 | 2 | 1 | 4 | 3 | 4 | 1 | 2 | 3 | 3 | 1 | 2 | 4 | 1 | 2 | 4 | 3 | | | | | 3 | 2 | 1 | 1 | 2 | 3 | 1 | 2 | 4 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 5 | 1 | 4 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 3 | 1 | 2 | 3.5 | 3.5 | 3 | 1 | 2 | 4 | 2 | 1 | 3 | 4 | 1 | 3 | 2 | 4 | 2 | 3 | 1 | 4 | 3 | 2 | 1 | | | | 1 | 3 | 4 | 2 | 1 | 2 | 3 | 4 | 1 | 3 | 3 | 2 |
| 6 | 1 | 4 | 2 | 3 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 2 | 4 | 3 | 4 | 1 | 2 | 3 | 1 | 3 | 2 | 4 | 1 | 2 | 4 | 3 | 4 | 1 | 2 | 3 | 3 | 2 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 4 | 1 | 2 | 4 | 3 | 1 | 2 | 4 | 4 |
| 7 | 2 | 1 | 3 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3.5 | 3.5 | 3 | 2 | 1 | 4 | 2 | 1 | 3 | 1 | 3 | 2 | 1 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 8 | 1 | 1 | 2 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 2 | 3 | 4 | 1 | 4 | 1 | 3 | 2 | 2 | 1 | 4 | 3 | 1 | 3.5 | 3.5 | 2 | 3.5 | 3.5 | 2 | 1 | 3 | 2 | 1 | | | | 1 | 2.5 | 4 | 2.5 | 1 | 3 | 2 | 4 | 1 | 3 | 3 | 3 |
| 9 | 1 | 2 | 1 | 4 | 1 | 2.5 | 2.5 | 1 | 2.5 | 2.5 | 2 | 1 | 4 | 3 | 4 | 1 | 3 | 2 | 2 | 3 | 1 | 4 | | | | | 4 | 3 | 1 | 2 | 3 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 3.5 | 3.5 | 1 | 2 | 3.5 | 3.5 | 1 | 2 | 3.5 | 3.5 |
| 10 | 1 | 2 | 1 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3.5 | 3.5 | 4 | 1 | 3 | 2 | 1 | 2 | 3 | 4 | 1 | 3 | 4 | 2 | 3 | 2 | 1 | 4 | 2 | 1 | 3 | | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 11 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 2 | 4 | 3 | 4 | 2 | 1 | 3 | 2 | 1 | 3 | 4 | 2 | 1 | 3 | 4 | 4 | 1 | 2 | 3 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 3 | 2 | 4 | 1 | 3 | 4 | 2 | 1 | 2 | 3 | 4 |
| 12 | 3 | 2 | 4 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 2 | 1 | 3 | 4 | 1 | 4 | 3 | 2 | 1 | 4 | 2 | 3 | 1 | 2 | 3 | 4 | 2 | 3 | 1 | 4 | 1 | 2 | 3 | 2 | 3 | 1 | 1 | 3 | 4 | 2 | 2 | 3 | 1 | 4 | 1 | 3 | 2 | 4 |
| 13 | 2 | 1 | 4 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 4 | 3 | 1 | 4 | 3 | 2 | 1 | 4 | 2 | 3 | 1 | 2 | 3 | 4 | 4 | 3 | 2 | 1 | | | | 3 | 2 | 1 | 4 | 2 | 3 | 1 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 4 |
| 14 | 1 | 1 | 2 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 4 | 1 | 3 | 2 | 2 | 3 | 1 | 4 | 3 | 4 | 1 | 2 | 4 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 4 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Aggregate | 18 | 19 | [illegible] | 45 | 11 | 32.5 | 17.5 | 14 | 37.5 | 37.5 | 19 | 25 | 51 | 45 | 51 | 18 | 24 | 37 | 21 | 30 | 33 | 54 | 16 | 30.5 | 41 | 47.5 | 6.5 | 27.5 | 30 | 40 | 29 | 24 | 25 | 16 | 26 | 24 | 20 | 32.5 | 47.5 | 40 | 26 | 33 | 38.5 | 48.5 | 16 | 31 | 42.5 | 51.5 |
| Overall ranking | 1 | 1 | 2 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 4 | 3 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 4 | 1 | 2 | 3 | 3 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 4 | 3 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Friedman $\chi^2_r/df$ | 17.74/3 | | | | 21.89/2 | | | 22.75/2 | | | 30.51/3 | | | | 23.57/3 | | | | 22.88/3 | | | | 20.70/3 | | | | 22.22/3 | | | | 1.07/2 | | | 5.09/2 | | | 17.67/3 | | | | 18.15/3 | | | | 33.23/3 | | | |
| Decision about Ho | P .001<br>Reject Ho | | | | P .001<br>Reject Ho | | | P .001<br>Reject Ho | | | P .001<br>Reject Ho | | | | P .001<br>Reject Ho | | | | P < .001<br>Reject Ho | | | | P .001<br>Reject Ho | | | | P < .001<br>Reject Ho | | | | P .05<br>Accept Ho | | | P .05<br>Accept Ho | | | P < .001<br>Reject Ho | | | | P < .001<br>Reject Ho | | | | P < .001<br>Reject Ho | | | |

- Test 2: The multiple comparative based on Friedman rank sum proposed by Miller and Wolfe (1976) to compare all the alternatives pairs for similarity.

The rationale for using these tests is that they avoid the assumption of normality on the cell densities and test 2 is only conducted when a statistically significant difference is found between the original $k = 3 - 4$ alternatives, and they work on inherently ordinal data such as these. The parametric analogs of these tests are the analysis of variance and complete blocks design test respectively.

Test 1: The next three rows after subject 14 in Table 10 give the cumulative sum of the ranks in each column (row 1), the overall ranking of these sums (row 2), and the value of the associated Friedman's $X_r^2$ statistic (row 3). The probability of occurrence under the null hypothesis Ho (no overall difference between alternatives) for these $X_r^2$ values are given in the last row of the same table. The decision about Ho and its significance level are also shown in that same row. The necessary calculations are shown in Appendix D2.

Test 2: Table 10 indicates that with the exception of question 11, 12 and 13a the probability values from the Friedman's test statistic are large enough to recommend a rejection of the null hypothesis of no difference between alternatives. Therefore, for the questions in which it is not possible to accept Ho, it is necessary to know which alternatives differ significantly from each other. The column sums in Table 10 once divided by $k$, are used to rank the alternatives and accordingly can be regarded as estimates of the ranks of the corresponding alternatives preferences in the population. That is, $R_j/N$ is an estimate of the mean rank for $j = 1,\ldots,N$ . Simultaneous tests (multiple comparisons) with an overall level of significance can be performed using these estimated alternative ranks or, equivalently, the column totals. When all possible differences between rank sums of two treatments (column totals) are taken, then the probability is at least $(1-\alpha)$ that the following inequality is satisfied by all pairs $(R_i, R_j)$ for $i,j = A, B, C, D; i \neq j$

$$|R_i - R_j| \leq Z\left(\frac{Nk(k+1)}{6}\right)^{1/2} . \tag{11}$$

Let T be the right hand side of this inequality. The constant Z is the quantile point of the normal curve that corresponds to a right-tail probability of $\alpha/k(k-1)$ , since the total number of comparisons is $k(k-1)/2$ . Th s Z value can be obtained from any Normal Distribution table for any k and $\alpha$ . For small k(k=4 or less) in the questionnaire the typical values of $\alpha$, Z can be read from a special table (see Table N for critical Z values for $p = k(k+1)/2$ multiple comparisons, in Gibbons (1976; page 432)), and the value of T can be evaluated.

At an overall level $\alpha$, all pairs of differences of column sums that are larger than the value of T are significantly different pairs, and the direction of difference is determined by the sign of $R_i-R_j$ . If some subset of the $k(k+1)/2$ possible comparisons of column sums is desired, expression (11) may still be used, but critical Z value must correspond to that $p = k(k+1)$ which is the actual number of comparisons actually made.

This above procedure provides the following results for the pairwise comparisons of alternatives A, B, C, D for the data in question 1:

Number of alternatives $k = 4$,

Number of subjects $N = 14$ ,

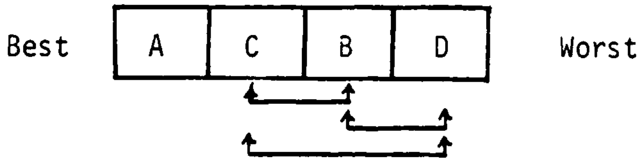
Number of pairwise comparisons $p = k(k+1)/2 = 6$ ,

Critical value (T) at level $\begin{cases} 20\% = 14.53 \\ 10\% = 16.35 \\ 5\% = 18.02 \end{cases}$

Values of $R_i - R_j$ ; $i = A,B,C$ ; $j = B,C,D$ ; $i \neq j$:

| B | C | D | |
|---|---|---|---|
| 21 | 20 | 27 | A |
| | 1 | 6 | B |
| | | 7 | C |

At all three significance levels the following ranking and relationships hold:



This result indicates that alternative A by far is preferred and it is distinctly different from the others. It also indicates that alternatives C, B and D do not have a significant difference between each other. Their similarities are illustrated by the bracketed arrows. The strongest of the similarities is indicated by the top most bracket (alternatives C and B are almost equally preferred with only a difference of 1 between their rank sum); less so but almost equally preferred is the middle bracket (alternatives B and D with only a difference of 6 between their rank sums). The bottom bracket indicates the weakest of the similarities and yet significant between C and D (about a difference of 7 between their rank sums). The results of similar analyses for the remainder of group 1 and all the other groups (with the exception of questions 8 and 10) are shown briefly in Appendix D3.

These relationships suggest that whenever alternative A of question 1 (i.e., any vertical order between the labels in the layout) is physically feasible no other layout using the alternatives C, B or D need to be generated in order to compare them as any comparison criteria based on question 1 alone must instinctively decide for alternative A. That is the relationships suggest that after obtaining a page layout using any order described by alternative C, we must necessarily try to obtain a feasible page layout using alternative B and also perhaps alternative D, then evaluate and compare them to decide which one of the layout solutions be kept. Table 11 shows for each question the alternatives in the resultant layout which is feasible are evaluated and accepted with or without the comparison test with the next alternatives (exception for questions 8, 9).

## 5.3 Generalization of the Page Layout

At the start of the layout process, the entire page is divided into rectangular grid squares which are separated by desired vertical and horizontal margins. Each grid square has the size of a standard label box specified by the system user.

The sub-procedure splitting routine provides the number of pictures and labels to fit in one page. At the end of the splitting process, the pictures are entered in the page one at each corner with the top oriented toward the top of the page. The initial choice of the location and position of each picture is decided according to the number of elements in the page and the desired location of the overview (if any), as examined in questions 13 (a, b and c) of the questionnaire.

Each picture's location, internal structure (i.e., distribution of its internal points), and relationships with other picture(s) in the

| Group | Question | Resultant layouts comparable and/or noncomparable | |
|---|---|---|---|
| 1 | 1 | A | CBD |
| | 2 | A | BC |
| | 3 | A | BC |
| | 4 | AB | DC |
| 2 | 5 | BC | CDA |
| | 6 | EFG | H |
| | 7 | IJ | JLK |
| | 8 | | |
| | 9 | BCD | A |
| 3 | 10 | | |
| | 11 | DCA | |
| | 12 | ACB | |
| 4 | 13a | AB | DC |
| | 13b | AB | CD |
| | 13c | AB | CD |

Table 11. Resultant layouts which need to be (or need not be) compared if the final page layout acceptance and/or rejection criteria is solely based on the type of the alternative used.

page are analyzed. The pictures whose positions and internal structures require a corrective repositioning are moved whenever possible to new positions. A corrective repositioning of a picture is required when there is not enough desired space around it, and/or, when its distance to its overview may cause the arrow from its boundary to that overview to be much longer than desired. In order to move a picture into a new position, one or several pushes are performed on it. The direction of the push is decided based on the distribution of its internal points. Each internal point is assumed to act like a unit force pushing the picture in a direction perpendicular to the closest of its boundaries and opposed to that side (see Figure 38). Therefore the direction of a push to be performed on a picture is the resultant of these forces. The distance of a push is decided by the position of the other elements in the page to insure no overlapping in the page.

Once all picture positions are established in the page, the position of every grid square is verified against the positions of the pictures. The grid squares which are found covered by (or too close to) the pictures are eliminated at this stage. They may however, be considered at a later stage when another repositioning occurs. The non-covered grid squares are recognized and may be considered available for selection to be a potential label slot.

## Placement Component of the Labels

The method of label placement at the current stage is the process of selecting every non-covered grid square among all the available grid squares considering their physical positions in the desired order. This order can be any particular order examined in the

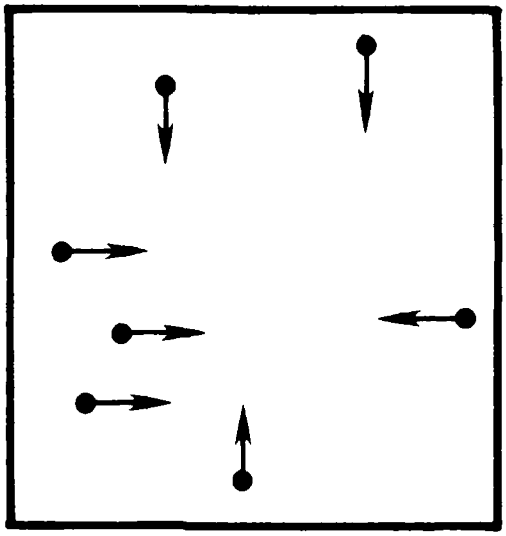


Figure 38. Illustration of the picture more as desired by its internal structure.

Each internal point attempts to direct the push away from the side it is closest to in the page.

For internal point

questionnaire (i.e., vertical, horizontal, etc.). The grid squares selected become the potential label slots which are considered in the (MAAP) discussed above.

### 5.3.1 Solution Procedure to the (MAAP)

When the pictures are repositioned in the page as described above and all the label slots are identified, the next step is to:

1. establish the picture-to-picture relationships (this is done by deciding the point of contact of every picture-to-picture arrow on the boundaries of the appropriate pictures).
2. eliminate the potential label slots which are crossed by, or much too close to, these arrows,
3. select the label slots among the potential label slots which fall in the path of the order being considered, and,
4. solve the (MAAP) to assign the internal points to the label slots.

At the end of this process all the criteria of the layout are evaluated and a decision is made about the acceptability[10] of the solution. If the solution is not acceptable, the pictures remain at their current locations, and the status of every one of the label slots is updated (i.e., changed from that of a label slot to a potential label slot). The next order(s) from the analysis of Table 11 is considered, some potential label slots are considered and the process in (4) is repeated. If no order remains the picture positions are revised to the next locations preference (if any) as established in Table 11 (i.e., 13a, 13b, 13c). If no such next preference is available, the best solution at hand (if

[10] Note: The solution procedure as seen in Chapter III, is supposed to follow the method of pre-emptive priorities. However, it is necessary to impose certain goal levels for further orders (if any just as good) to be examined.

any) is retained, or the subprocedure at hand is considered to have failed the "Validation Procedure" (recall Figure 14). The steps of the (MAAP) are given below; the corresponding flow chart is seen in Appendix C2. These steps are given in global form as each is more or less a procedure.

### 5.3.2 The Steps of the Solution of the (MAAP)

Initialization Step (Step 0)

Identify the number of elements in the subprocedure at hand and their relationships. Update the status of all the grid squares, all the label slots, set the initial indices and go to the main steps.

Main Steps

Step 1 Analyze pictures' positions and relationships, and decide the corrective repositioning to be attempted. Perform every possible corrective repositioning, and go to step 2(a).

Step 2

(a) Compare every grid square's position with the position of every picture and update its status (non-covered grids are labelled "Free").

(b) Select and count the free grids (FGRID) which fall under the current order and compare with the desired number of labels in the subprocedure (NNEED). If FGRID < NNEED, go to step 3; otherwise go to perform the FAA procedure in step 6.

Step 3 Update the ordering index for the labels (INDXL) to next order as recommended in Table 11 and go to perform from step 2(b); if no next order for the label is available in the table, go to step 4.

Step 4 Update the ordering index for the pictures (INDXP) to next order as recommended in Table 11 and go to repeat from step 1; if no next order for the label is available in the table, go to step 5.

Step 5 Accept the solution (if any) currently at hand as the best solution for this page and go to step 9; otherwise recommend a reconstruction procedure to further decompose the current subprocedure and exit from the (MAAP).

Step 6 Attempt to obtain a solution to the FAA[11] problem; if no FAA is found go to repeat from step 3; otherwise go to step 7.

Step 7 Perform the steps of the swinging algorithm to solve the MIAA, the MTDAP and the MTDA problems (in this order) as necessary[12]. go to step 8.

Step 8 (a) If no solution is at hand prior to the current solution, go to 8(b); otherwise compare the solutions at hand and select the best. Go to step 8(b).

(b) Decide from table 11, if it is recommended to try another alternative order. If so, go to 9; otherwise record the solution at hand, update the indices (as required), and go to repeat from step 2(b).

Step 9 Find and perform the necessary adjustment(s) to bring the label slot (in the requirements) closer to the pictures for better marginal space between the elements in a page. Report the results and exit.

[11] Note: In Chapter III, the availability of a solution to the (AAA), which is an FAA was never posed, because the unique assumption of $N \leq M$ was always sufficient. Here,this condition is not sufficient; it is only necessary. This matter is discussed in a later section.

[12] Note: If for example $NX = 0$ from step 6, then the MIAA procedure is skipped.

### 5.3.3 Remarks

The steps used to solve the (MAAP) as seen above are more general than the steps used earlier for the (AAP). This is due to the following:

a) Several orders are used in addition to the clockwise arrangement previcusly used in the AAP. In addition the label slot which becomes candidate is only selected if it falls in the path of the desired order, and it is verified to be not crossed by a picture-to-picture arrow.

b) A label slot ($\ell$) selected to be part of a new assignment (recall the exchange process in Swinging Algorithm), is first submitted to test for intersection with every assignment in the layout, to qualify for that assignment. Also the assignment is not to take place if the assignment is to cross a label slot j such that $x_{ij} = 1$ is a real assignment. These and similar tests are used throughout the program and are called the "Label Slot Availability Tests' (LSAT).

c) Each internal point considered for assignment to a label slot has two additional indices which are verified previous to every exchange involving the internal point, and updated after that exchange. These indices are used for the label slots of the special types (i.e., Note, Warning, Voice Response, ..., etc.), which must precede or follow the label slot assigned to the internal point. These label slots are also included in the (LSAT) during the pairwise exchanges.

d) Method A and Method B seen in section 4.3.5 are both used to solve the (MAAP). Method A is the method used for every order except for the clockwise order allowed to begin from any label slot (i.e., Alternative 4D in Table 11, see Appendix D1). Method B is used for this order only. Both methods are programed to use an improvement of Method C.

## 5.4 Validation Procedure

The decision making process about the comparison of the solution at hand in order to select the best, and/or go for more alternatives as suggested by results in Table 11 is referred to as the Validation Procedure. This procedure as developed in the program is based on the first two objectives only of the (MAAP) as discussed in Chapter IV. An FAA is sought at all times, but a goal level (called NXOPT in the program) is set to be acceptable for the number of intersection in the layout. This number can be fixed at any integral value desired by the system user. The validation procedure is performed in step 8. A subprocedure is said to fail the validation test if no solution is obtained which is a FAA or which satisfies the user's NXOPT load.

## 5.5 The Reconstruction Procedure

The Reconstruction Procedure is a simple procedure performed as a corrective step on the subprocedure which has failed the validation procedure. It is done in the program in a subroutine called 'RECONST.' One or more of the following steps are executed.

Step 1. Drop the last label only, if it is of the type Action and the next label is also an Action, or,

Step 2. Drop the last two labels, if they are of the type Action followed by Note (or Response, Warning, ... etc.).

Step 3. Drop the picture related to the label(s) dropped in step 1 or 2 if there is no other label linked to it, or refile it on top of the temporary storage (see Figure 16).

Step 4 Backspace appropriately in the data base as required.

## 5.6 Summary

In this chapter a method to solve the (AAP) of simple page layout is generalized to the layout of a complex page. To develop this method, a questionnaire was first submitted to qualified participants and analyzed for the different alternatives involved in the decisions within a page. The results from the questionnaire were used to extend the algorithm discussed in Chapter IV to handle the multiple picture scenario. The steps of the method in procedure form are given. The next chapter discusses the results obtained from the layout of the three procedures used in Chapter III.

# CHAPTER VI

# CONCLUSION

## 6.1 Preliminary Results

The general page layout program was coded in FORTRAN IV compiled and run on a CDC CYBER 174 computer system. The program compilation time was about 22.0 CPU seconds and its storage requirement is about 53.4 K words (Each word on the CDC is of 60 bits length). The program was tested on many randomly generated pages and consequently on the real procedures. The program output listing and illustrative example (13 task steps procedure) are available in Sylla and Babu (1982).

The program was implemented on the three procedures which were used as data in Chapter III. The time for their layouts (with 70% splitting rule) were: 2.646, 5.136 and 19.72 CPU seconds for 13, 21 and 78 task sequences respectively. The times taken for the other percentage runs were slightly higher for lower percentage split (60%, 50%) and almost the same for (100%-80%). Particular interest was given to the 70% splitting rule which was used and tested on different labels sizes (recall Assumption 2 in Chapter V). Up to 8 points were allowed as contact points on the boundary of thc labels (see Sylla and Babu, 1982). The output pages of the MAAP with (NXOPT = 1) and no picture-move are seen in Appendix E . The further improved outputs pages with the picture-move allowed, and keeping (NXOPT = 1), are seen in Appendix E .

The quality of the output pages in terms of the 4 objectives depends, as expected, on many parameters which include the size of the objects (pictures and labels) involved and the number and distribution of the internal points. It was frequently seen that the number of intersections are reduced at the cost of worse alternatives: reading from bottom to top (least prefarred alternative). However, the program is flexible enough to attempt different initial positions (orders) and different moves. Efforts were made to include many possible moves of the pictures to render many labels slots available. The program is yet to be further tested on additional procedures and then field tested before a full assessment can be made under service conditions.

## 6.2 Areas of Improvement and Computational Efficiency

Improvements can be made to remove the assumption 2 and allow for different label sizes. This is possible by aading to the Swinging Algorithm the capability to modify the sizes of the label slots during the exchanges. If this is included, the exchange procedure will be reduced to exchanges between the adjacent label slots only. Therefore, a special device may be needed to generalize the exchange process in that situation.

Assumptions may be relaxed to include nonrectangular objects (i.e., irregular objects). The presenc layout algorithm can be used for such objects. To do so, it is sufficient to fit each irregular object into a minimum square rectangle; all other parts (i.e., data collection, procedure splitting, layout, etc.) will remain unchanged.

It is also possible to relax the assumptions and make the algorithm adopt non-straight arrows. For instance an arrow could be chosen to be piecewise linear and continuous, having more than one component. The swinging algorithm can be modified to re-arrange the components (as it reassignes the internal points to label slots) during the optimization procedures (MIAA, MTDAP and MTDA).

Several important questions remain to be answered in future for obtaining good layouts (all criteria considered) and for computational efficiency. The first question concerns the preventive identification of the occurrence of Locks and the preventive steps needed to avoid them and still guarantee "good solution".

The second very important question is how to characterize whether or not the number of intersections (NX) reached in the final layout is truly optimal when NX is greater than zero. No effort is made in the current research to characterize the optimality of the final layout given the distribution of the internal points in the picture(s) and the relative positions involved. Unless such a breakthrough is made it is not possible to specify a proper stopping rule for the MIAA procedure and consequently prescribe efficient computer time.

Another important question is related to the ranking of the priorities of the four objectives. Clearly for certain type of pictures and/or distribution of the internal points it may not be possible to reduce the number of intersections to meet the MD's desired small number of intersections (NXOPT). In this case the reconstruction procedure may always be needed; the consequence of this are many pages per procedure (with very few elements in the pages), and possibly long arrows on the outside of the picture (4th objective). Therefore there is indeed a need to study the question of the trade-offs between the objectives. This can be done by submitting several procedure layout pages to qualified personnel (or to students in training) and receiving the necessary feedback to modify the priorities if as required. For instance, it may be found desirable to combine the 3rd and 4th objectives into a single distance objective rather than handling them separately as done in the current research. Or it may be good to set up table look up of rankings to be included at the end of the solution and probe the selection of best alternatives.

For computational efficiency it will be interesting to investigate the modification of the current pairwise exchange technique of the Swinging Algorithm to include higher order (e.g., three or four) exchanges. This may help to reduce the phenomenon of a Lock during the solution for the MIAA.

As specified earlier, exact solution methods are found to guarantee optimal solution. Therefore, for computation experience, it may be of interest to examine the results of different exact solution methods such as Branch and Bound methods. It is suspected that the nature of the arrangement required between the assignments could be used to build quick fathoming rules, and reduce significantly the number of branches to be examined.

## 6.3 Other Areas of the Model Application

The current model of the AAP and MAAP can be met in the general context of the location and allocation problem (which includes the plant layout problems). Few examples of such type of problems include the problem of designing the intra-city (or inter-city) road systems to link different places in the city with minimum distance roads and fewest possible number of intersection points. Similar problems frequently occur in plant layout with the installation of conveyor belt systems (e.g., glass materials transportation); placing electronic elements on a backboard so that the total connector length (and possibly wire intersections) is minimized.

The major differences between the AAP and the general QAPs is the additional ordering requirements existing in the AAP. Although the Swinging Algorithm was designed to address this special requirement, its exchange method remains general to handle many types of layout problems. With proper modifications, the Swinging Algorithm can be used to solve many problems which fit the general QAP formulation.

## 6.4 Conclusion

The layout problem of the simple published aids for technical Job Performance and Procedure Training was investigated. A model was developed to make the computer sequentially split a page from a long procedure, and lay it out in a similar manner to the way the intelligent human designer would do. A human-based-heuristic was designed for the splitting task. A mathematical formulation was derived for the layout problem and was solved by a pairwise exchange heuristic. An attempt was made to systematize the solution process at every level of the layout. The model was seen to evolve from an interdisciplinary effort of Ergonomics, Traditional I.E. and Operation Research.

# APPENDICES

# APPENDIX A

## Subjects, methodology and Materials Used in the Questionnaire

### Subjects

A total of 14 participants (subjects) have analyzed the three tasks sequence and have also offered some insightful individual comments. The participants selected have some experience in the practice of Ergonomics and/or in the design of the Procedure Training Aids. Because of the high individual average experience of the participants in the subject matter involved, the total number of participants can be considered to be representative of a large user population. The participants areas of expertise and affiliations are given in Table A1.

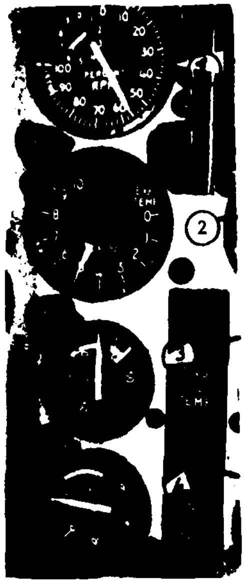
### Methodology

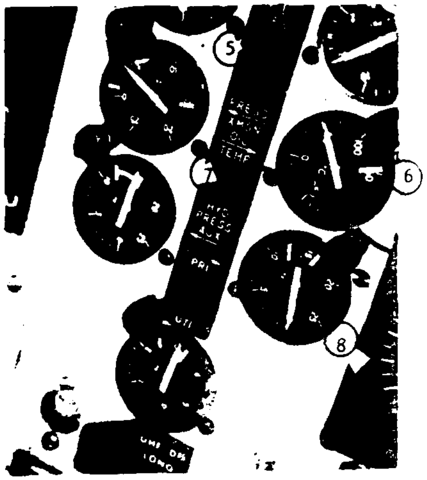
The questionnaires were sent to praticipants by mail. All the answers of the questionnaire (100%) were received and the percentage response to the questions is almost 100%. Additionally some useful comments are made but will not be subject to discussion in this report. They have been used to aid the interpretation of the statistical data.

| Participant | Area of Expertise | Affiliation |
|---|---|---|
| 1 | Training JPA, PTA | TAEG |
| 2 | Training JPA, PTA | TAEG |
| 3 | Training JPA, PTA | TAEG |
| 4 | Training, | TAEG |
| 5 | Syst Anal, JPA, PTA | TAEG |
| 6 | Psych, Training | TAEG |
| 7 | Psych, Training | TAEG |
| 8 | H.F., Training, Ergonomics | I.E., SUNYAB |
| 9 | Psych, H.F. | I.E., SUNYAB |
| 10 | H.F. | I.E., SUNYAB |
| 11 | Optimization, Operations Research | I.E., SUNYAB |
| 12 | Optimization, Operations Research | I.E., SUNYAB |
| 13 | H.F., Training | CALSPAN, BUFFALO |
| 14 | H.F., Training | CALSPAN, Buffalo |

TABLE A1. Participant (Subject) References

On Center Console
1





On Center Console 1

1. Action

   Pilot check Ng 56 ± 3%

2. Action

   Pilot check T5 (EXH TEMP) approximately 500°C

3. Action

   Pilot check ENG OIL TEMP rising or within range (normal range 35°C to 121°C)

4. Action

   Pilot check ENG OIL PRESS 10 psi or above (normal range 25 to 60 psi)

5. Action

   Pilot check PRESS XMSN above 12 psi (normal range 45 to 90 psi)

6. Action
   Pilot check OIL TEMP XMSM rising or within range( normal range is 40°C to 120°C)

7. Action

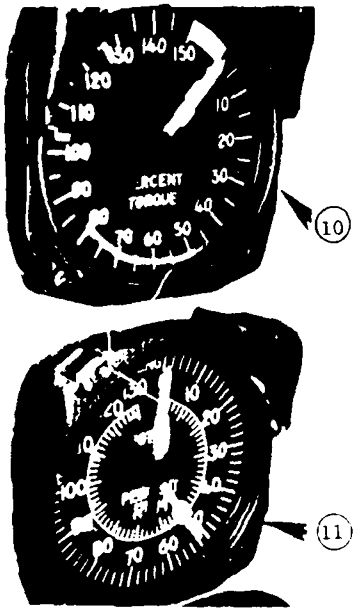
   Pilot check AUX HYD PRESS Normal (normal range is 1300 to 1600 psi)

8. Action

   Pilot check PRI HYD PRESS Zero if blades folded (normal range 1300 to 1600 psi)

9. Action
   Pilot check UTL HYD PRESS ____ (normal range is ____ to ____ psi)

On Center Console 1



On Pilots/Copilots Instrument Panel 12,3

10. Action

Pilot/Copilot check No. 1 Torque __

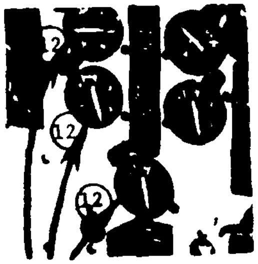
11. Action

Pilot/Copilot check No. 1 Nf (free Turbine) speed approximately __ to __

12. CAUTION
Upon initial indication of a lack of accessory drive when operating in accessory, the engine should be shut down immediately and not restarted

13. Voice Response

"CHECK"



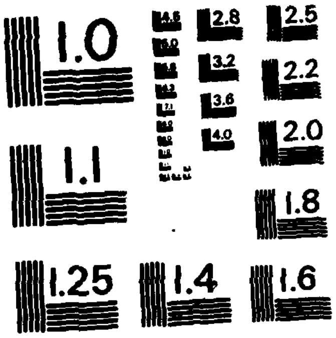
On Center Console 1

## APPENDIX B1

### Definition of the Explosion Level Concept

As described in Section 1.2 the type of materials involved include pictures (illustrations, diagrams etc.) and several types of task steps. In any JPA or PTA procedure, a picture is drawn to present the equipment (or device) discussed in the task steps in form of a general view, specific view, item enlargement view or item exploded view (also called item close-up view). The decision about each view is made with respect to the details desired in the task step to refer to a specific equipment (or device), or an indication on an equipment (or device). Figure B1 shows an example of a general and specific locator illustration with item enlargement and exploded view. Figure B2 shows the planetary locator illustration layout of the example in Figure B1. In reality every picture can be assumed exploded (or "close-up") to a certain extent. For instance in the example of the Figure B1, the general aircraft locator does not come from a close-up view and cannot be considered as if exploded. Therefore it can be said that its explosion level (or close-up level) is zero. However one close-up (one explosion) was made to present the specific locator illustration; two close-up (two explosions) were made to present the enlargement view; up to three close-up (three explosions) were made to present the exploded view. Figure B2 shows the planetary locator illustration layout with the corresponding close-up (explosion [illegible] in nearby square boxes. This explosion scheme serves [illegible] details a specific element and can be carried out to a [illegible] by the JPAs and PTAs designers. As such, th[illegible]

AD-A139 347    COMPUTER AIDED LAYOUT OF PROCEDURE INFORMATION FOR    3/3
TRAINING AND JOB AIDIN..(U) STATE UNIV OF NEW YORK AT
BUFFALO AMHERST DEPT OF INDUSTRIAL E..  C SYLLA ET AL.
UNCLASSIFIED    DEC 83 TAEG-TN-11-83 N61339-81-C-0091    F/G 5/9    NL


1.0
2.8
2.5
3.2
2.2
3.6
2.0
4.0
1.1
1.8
1.25
1.4
1.6

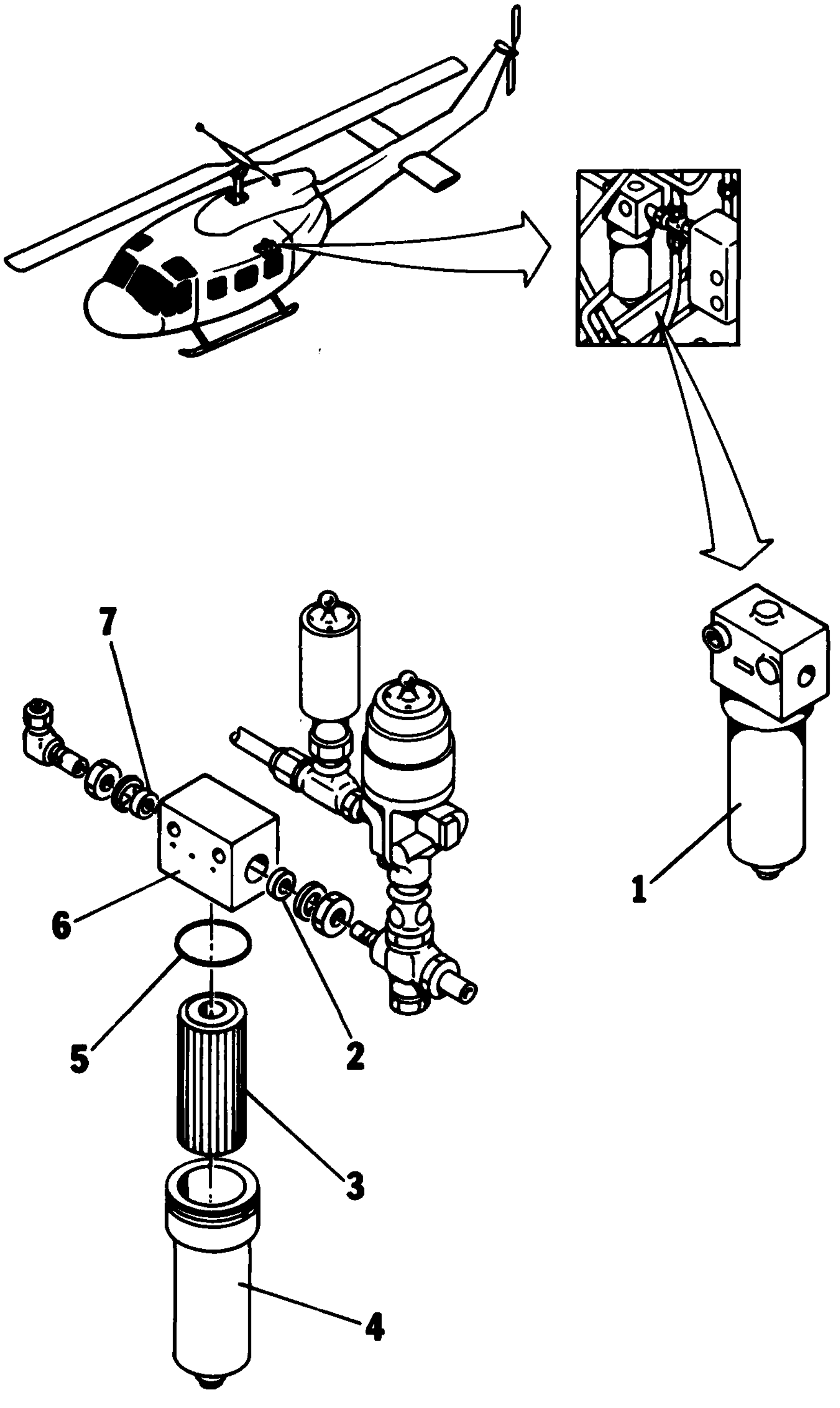


Figure B1. General and Specific Locator Illustration with Item Enlargement and Exploded View

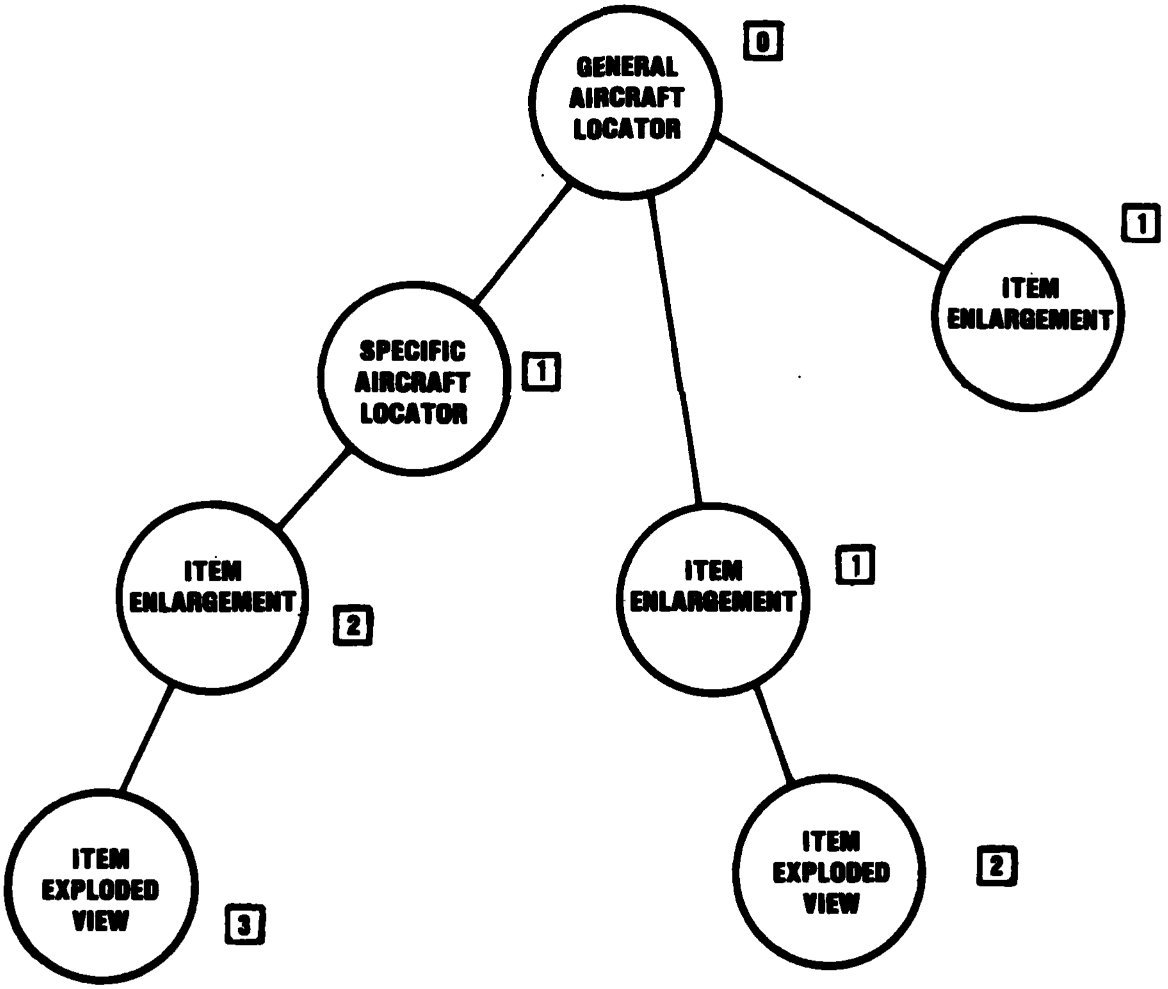


Figure B2. Planetary Locator Illustration Layout
The General Aircraft Locator Illustration
Is Also Referred To As The Overview Picture

picture in a JPA or PTA procedure can be an integer number from 1 to N; a picture which explosion level is say 5, has been enlarged 5 times from a particular place on the ovewview to its present view (detail).

## APPENDIX B2

### Assumptions Used in the Preparation of the Data Base and the Splitting Algorithm

The following assumptions were used to efficiently organize the data base and design algorithm to be used to split the lengthy procedures as discussed in Section 3.2:

(1) In every procedure to be split, it is assumed that at least one picture goes along with every continuous sequence of 7 task steps,

(2) Any non illustrated task step (possibly a Note, a Warning, a Caution or a Voice Response ... etc.) which comes immediately before or in between the task steps related to a specific picture, is assumed to be also related to that picture unless it is otherwise specified by the user.

(3) The typical example of a procedure with task sequence and corresponding pictures and specific explosion levels (see Appendix B1) is illustrated in Figure B3. This figure shows the task steps and their sequence numbers as assumed to exist in the JPAs and PTAs procedures. The figure also illustrates the picture sequence numbers in small circles and their explosion levels in small squares next to them (e.g.,①, $\boxed{1}$). The pictures sequence numbers are consequence of the reference task sequence numbers. The following rules are assumed used in numbering the pictures:

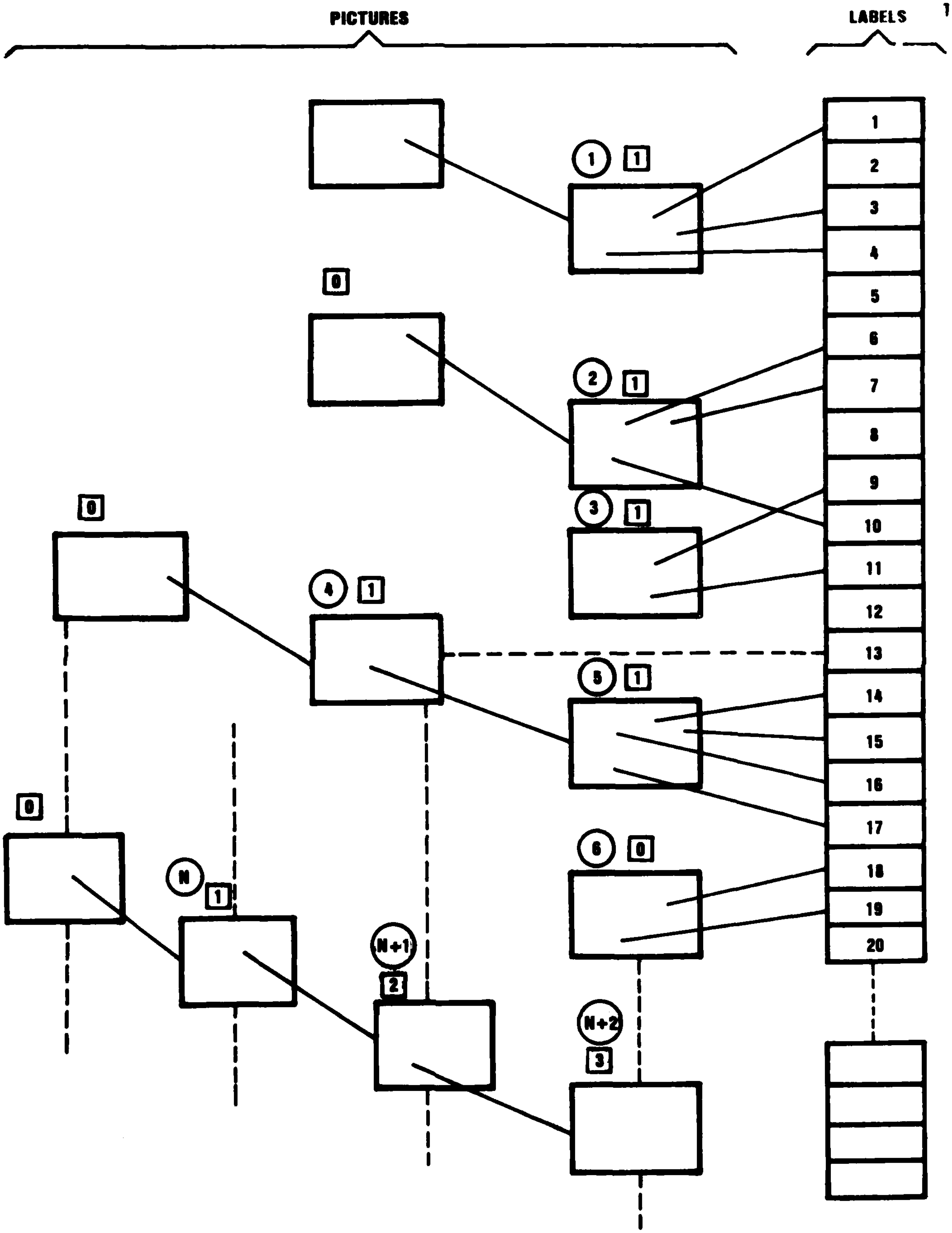


Figure B3. Sequence Numbering Schemes and Explosion Levels in a Typical Lengthy Procedure

(3a) The pictures are numbered in a continuous sequence startinn from the picture linked to the first label(s).

(3b) Among the picture(s) in linked to any label(s), the picture with highest explosion level if any is number first down to the lowest picture explosion (see Figure B3).

(3c) The highest explosion level of a picture allowed in the page is 3. This is the consequence a maximum of 4 pictures as recommended by the participants (see Section 3.2.2).

(3d) Overview pictures (main pictures in the procedure) are not numbered in the sequence.

(4) The information about every lower level exploded picture is supplied along its immediate next higher exploded picture.

(5) No two overviews (two different main pictures) will be allowed in the same split.

(6) If during the splitting process an independent picture (picture which is not exploded and which is also not an overview) is first to enter in the split no additional picture with the exception of immediate independent picture(s) if any will be added to the split.

(7) The sequence of the labels linked to any given picture is assumed not interrupted by the sequences of labels linked to two pictures.

(8) Every label is assumed to be part of the sequence of labels linked to one picture alone.

# APPENDIX C1

## Notations of terms used in equations 3, 4, 5 and 6

$W_{ij}$ — cost of interaction (an intersection) between the arrow ending in internal point $i$, and the arrow ending in internal point $j$.

$I(a(i),a(j))$ — is a zero-one variable which indicates whether an intersection is occurring between the arrow ending in point $i$, and the arrow ending in point $j$.

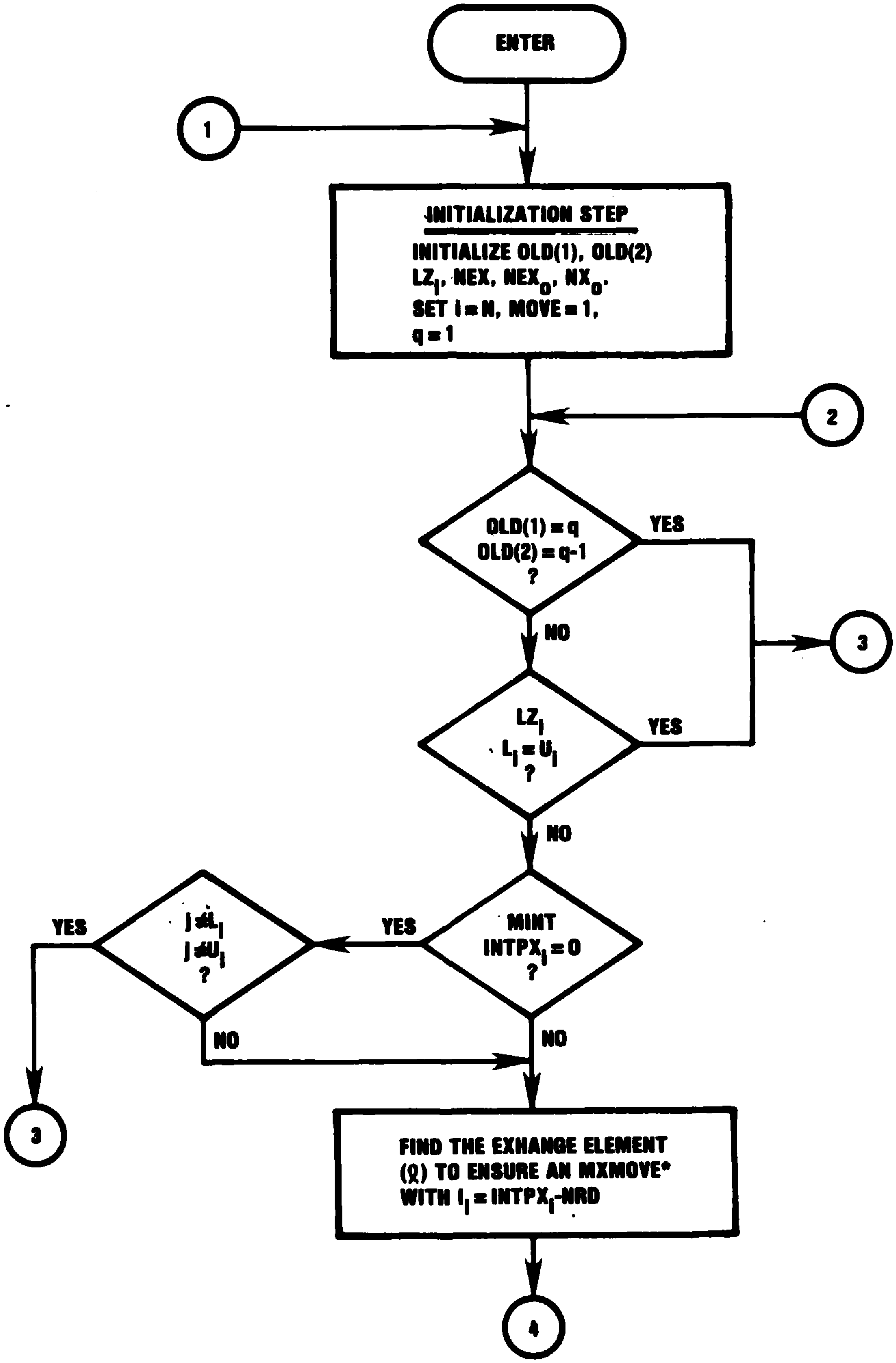
$d(a(i))$ — total length of the arrow ending in point $i$.

$\bar{d}(a(i))$ — length within the picture of the arrow ending in point $i$. Note that $\bar{d}(a(i))$ is a part of $d(a(i))$; $\bar{d}(a(i)) < d(a(i))$ (see Figure 23).

$C(a)$ — Cost of any violation of (deviation from) desired specifications of an arrangement.

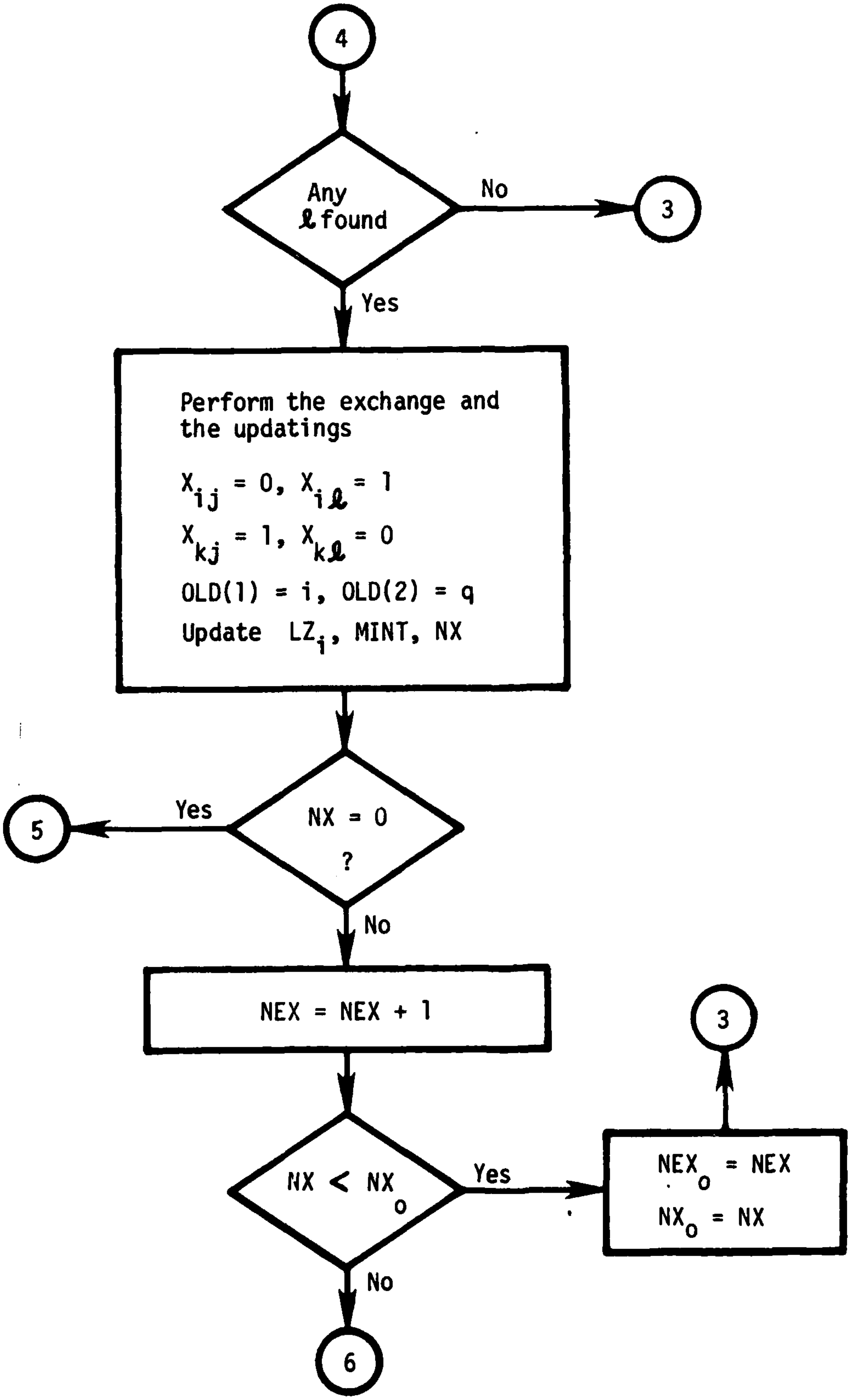
# APPENDIX C2

THE SYSTEM ROUTINES DISCUSSED

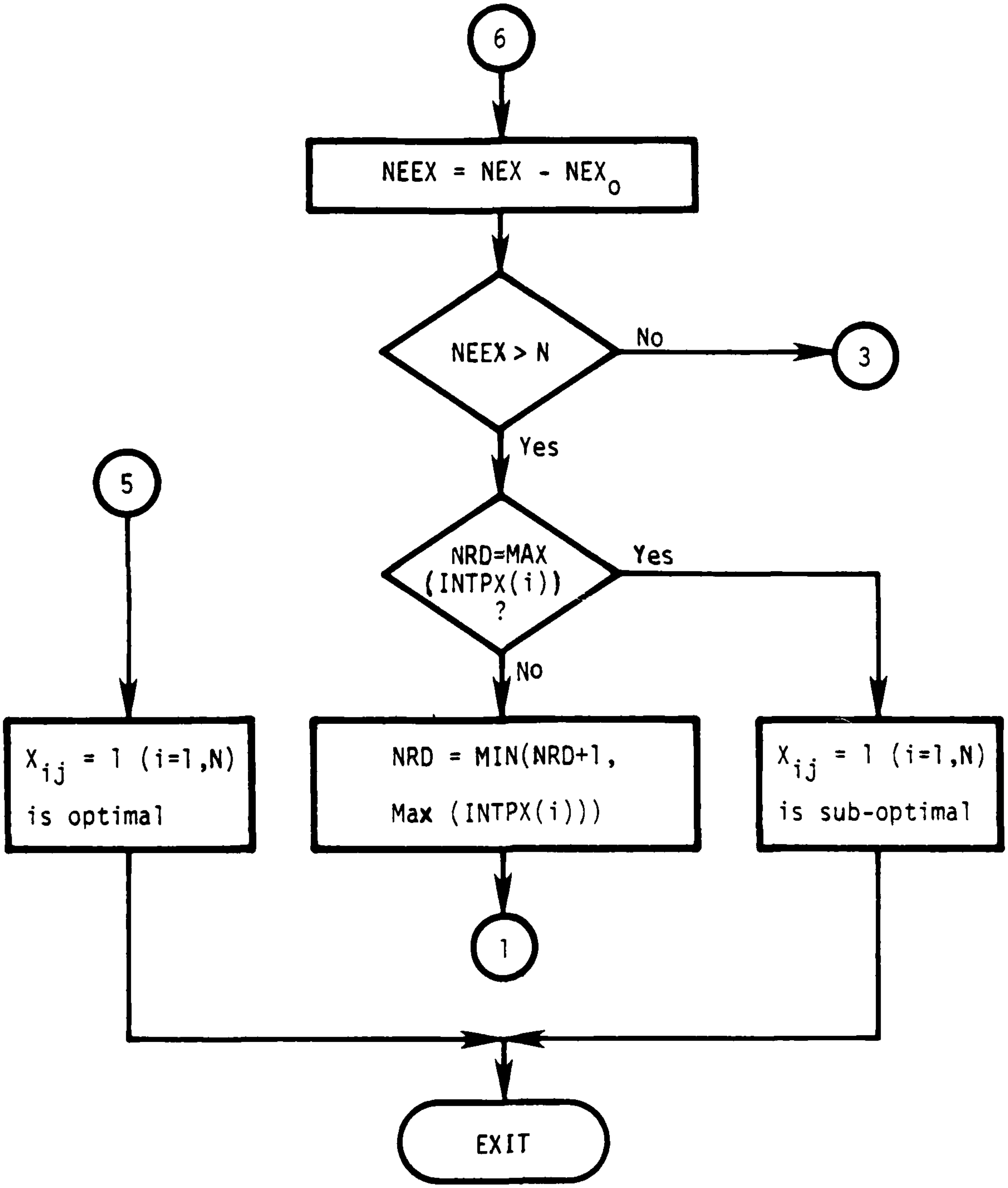


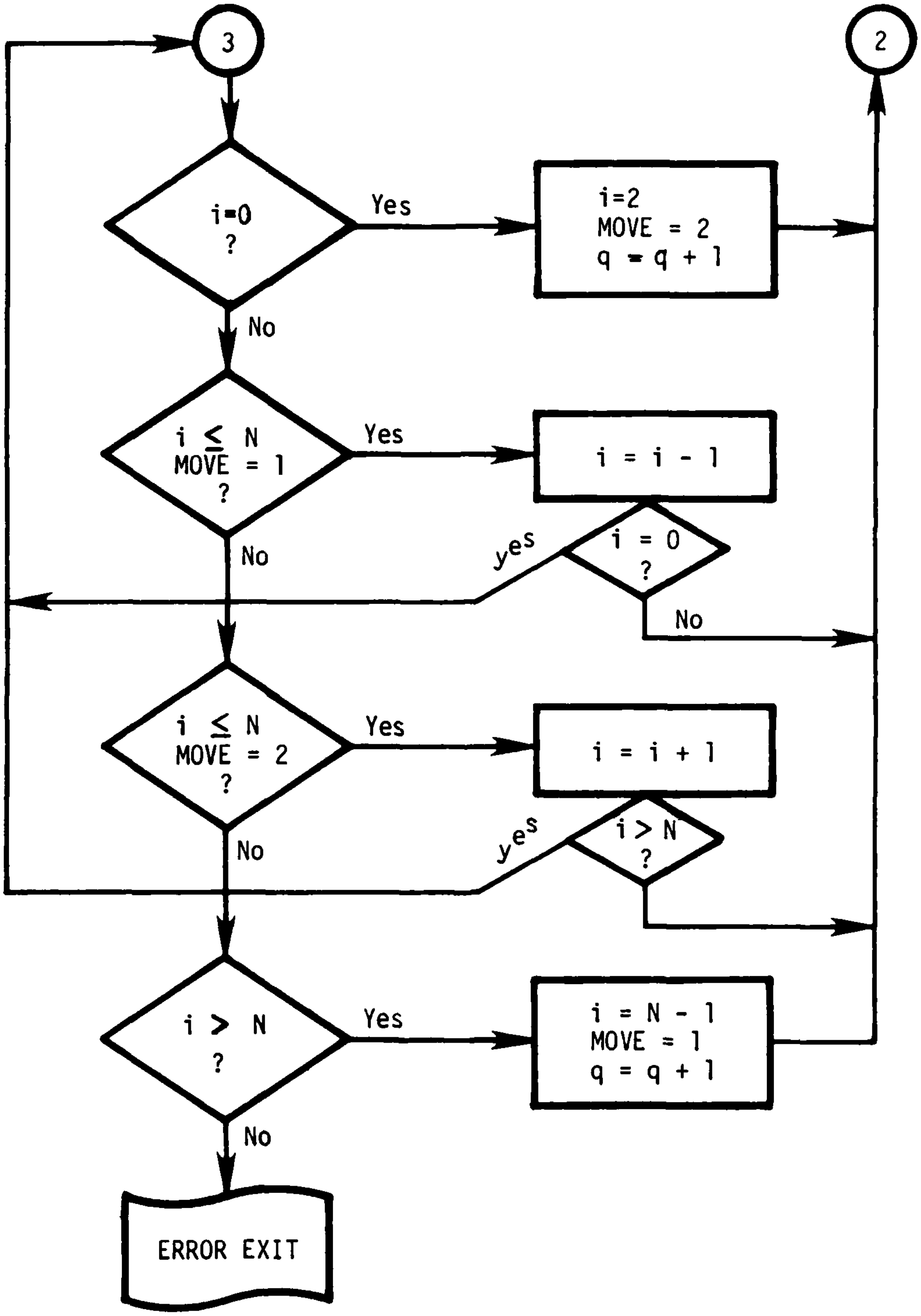
*MXMOVE: MOVE (OR EXCHANGE)TO CREATE THE MAXIMUM POSSIBLE OPENING OF THE LIMIT ZONE ($LZ_i$).

The MIAA Procedure Steps (cont.)



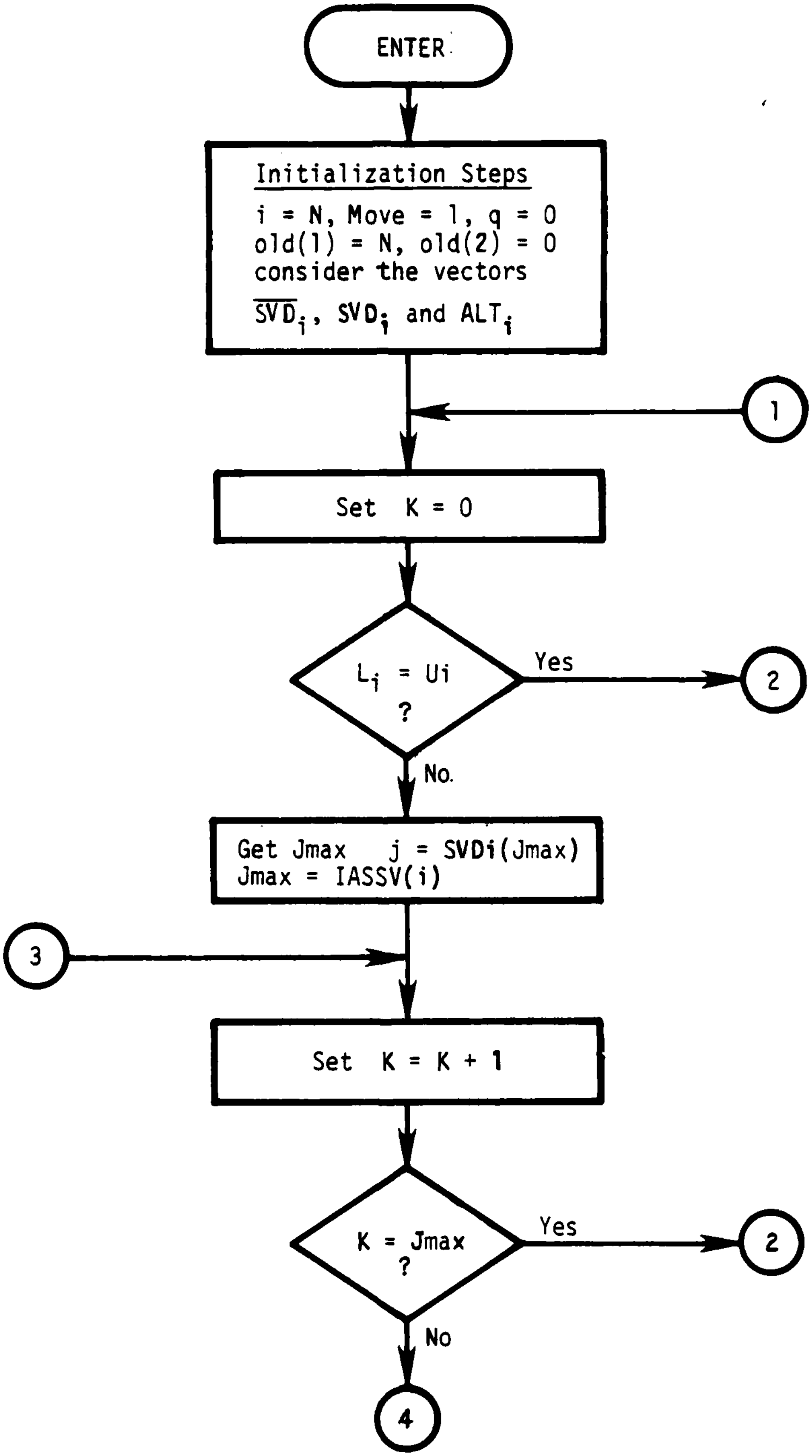
The MIAA Procedure Steps (cont.)

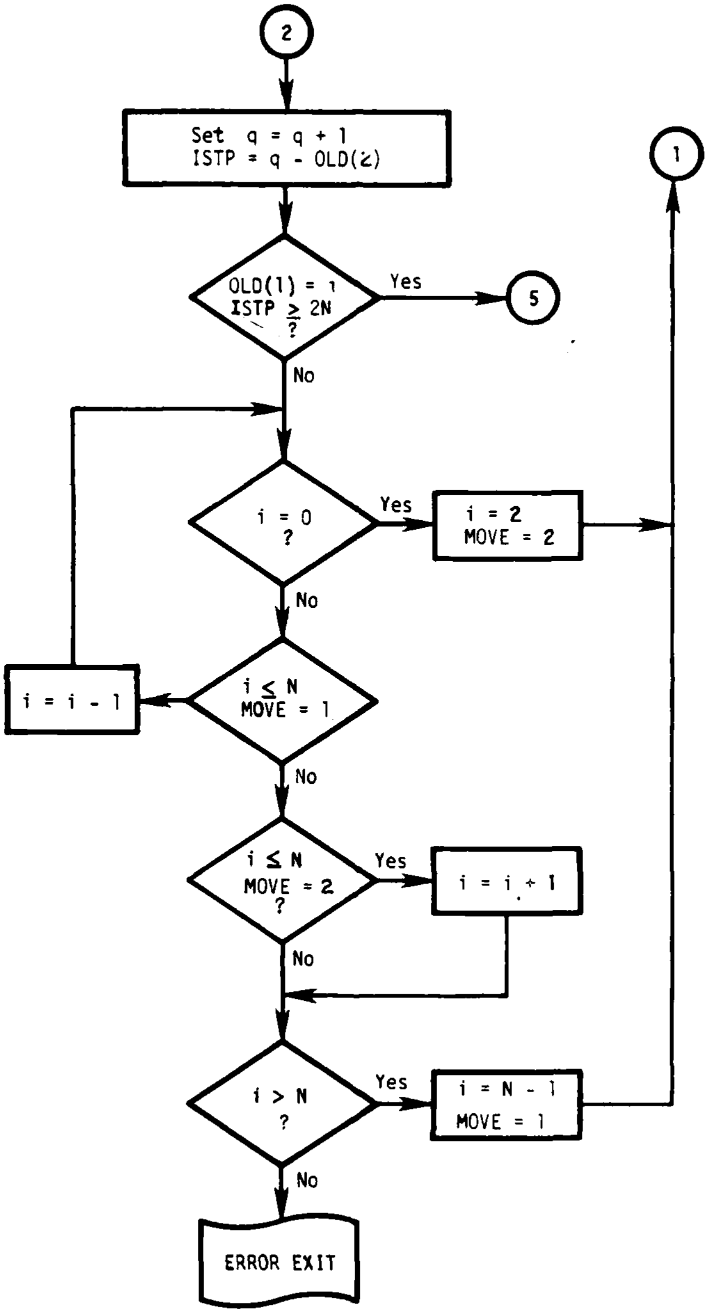

6
NEEX = NEX - NEX$_o$
NEEX > N
No
3
Yes
5
NRD=MAX (INTPX(i)) ?
Yes
No
$X_{ij}$ = 1 (i=1,N) is optimal
NRD = MIN(NRD+1, Max (INTPX(i)))
$X_{ij}$ = 1 (i=1,N) is sub-optimal
1
EXIT



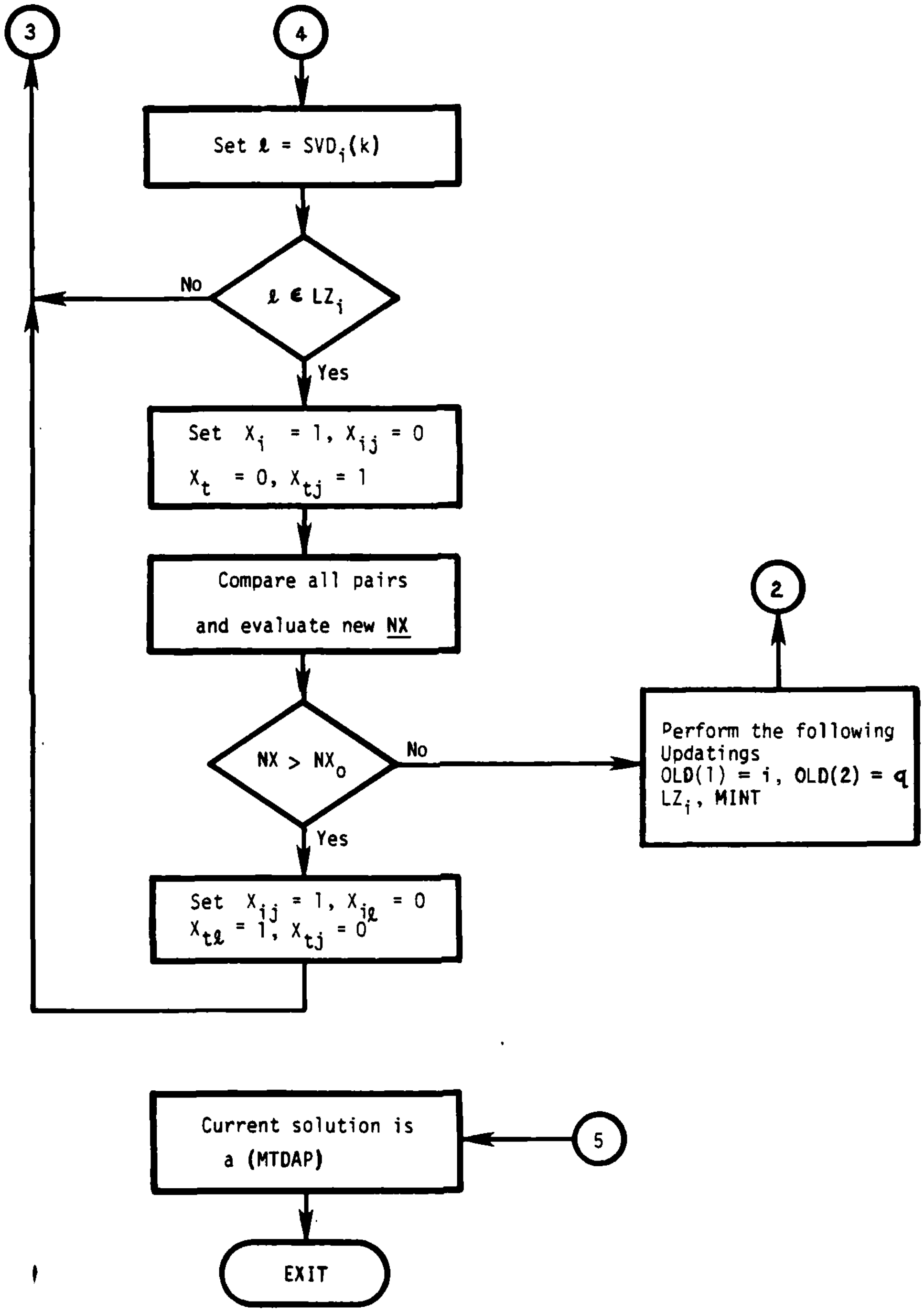
The MIAA Procedure Steps (END)

The MTDAP Procedure Steps



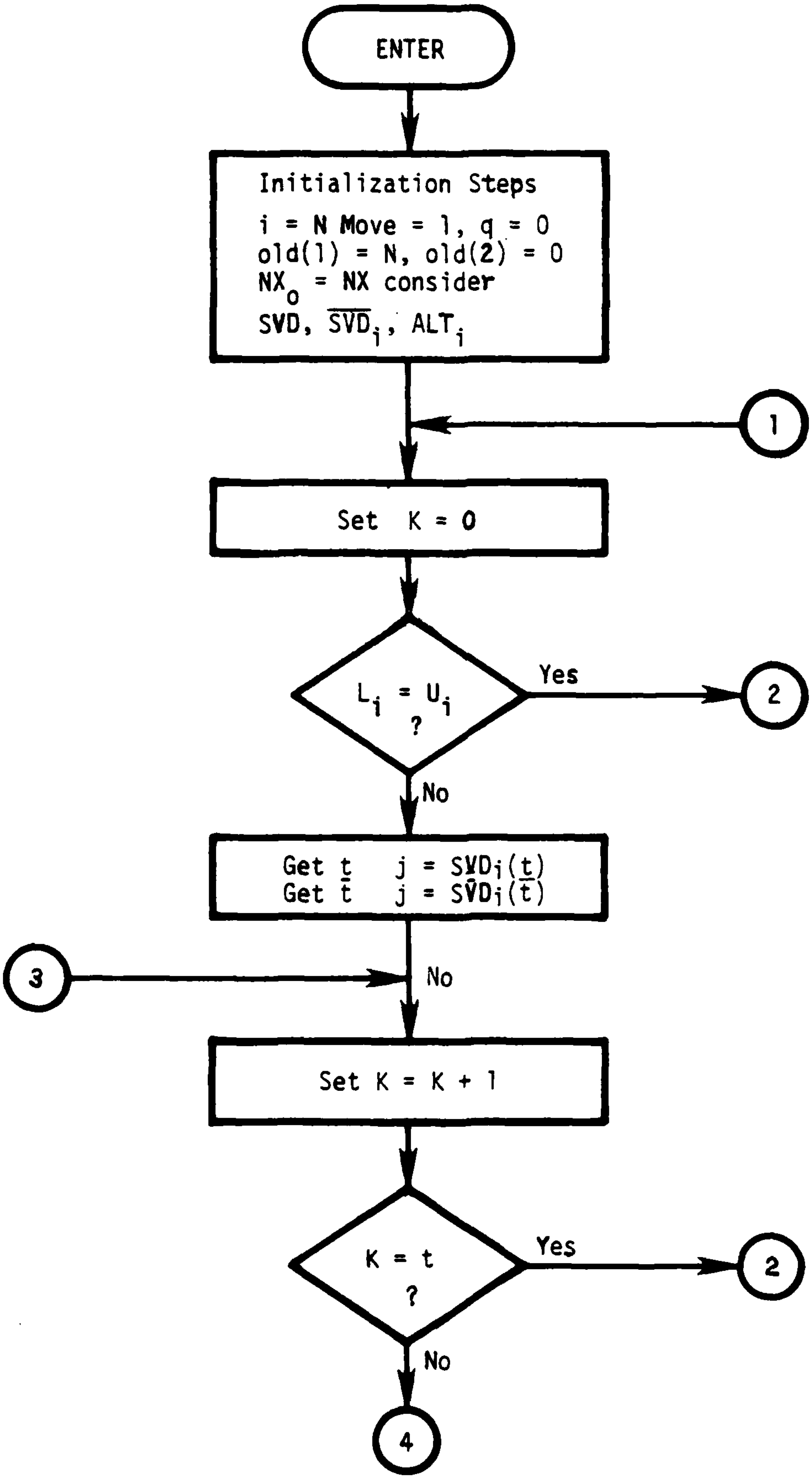


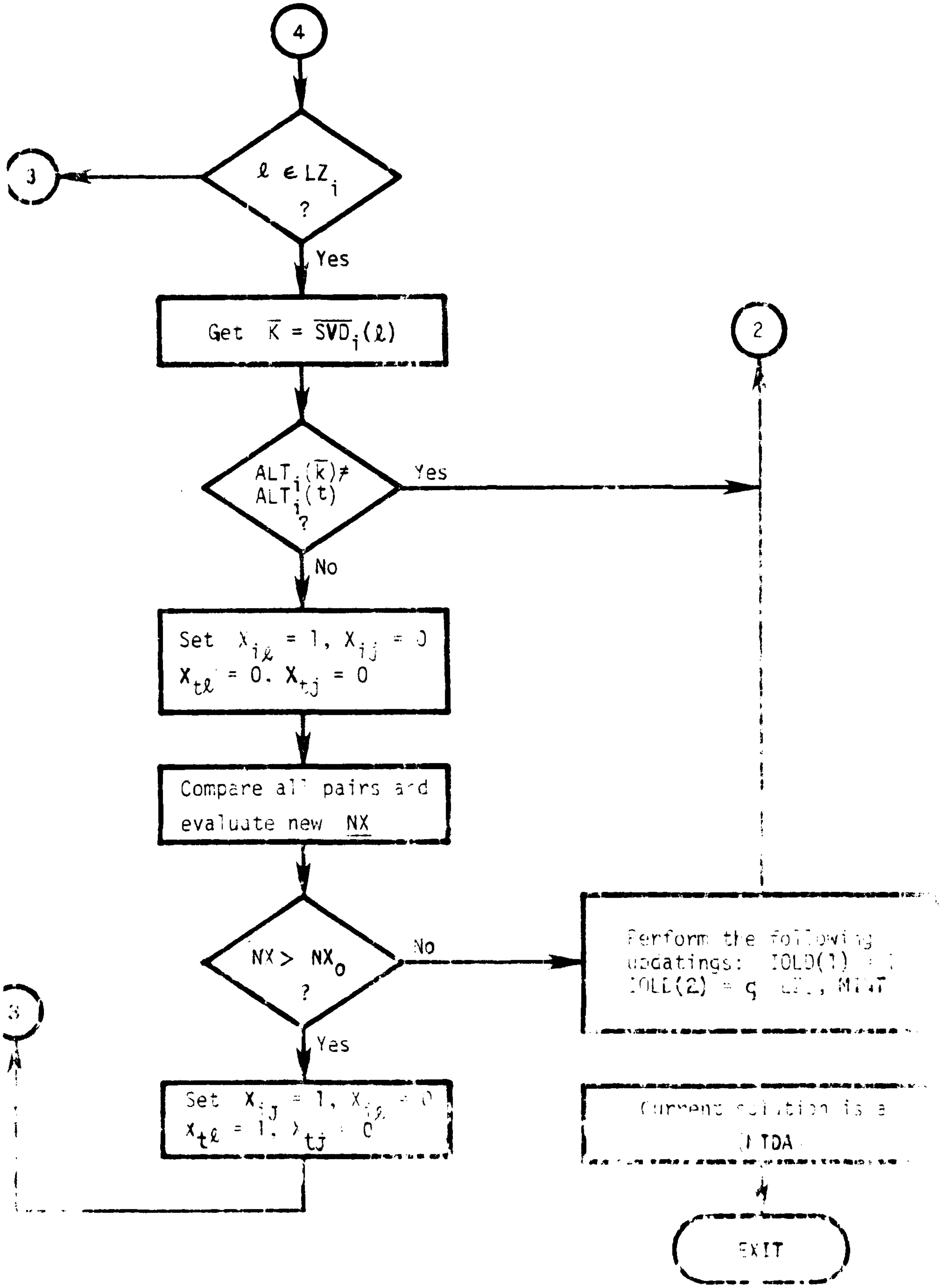
The MTDAP Procedure Steps (Con't)
The steps in this page are also used in the MTDA procedure



The MTDAP Procedure steps (END)

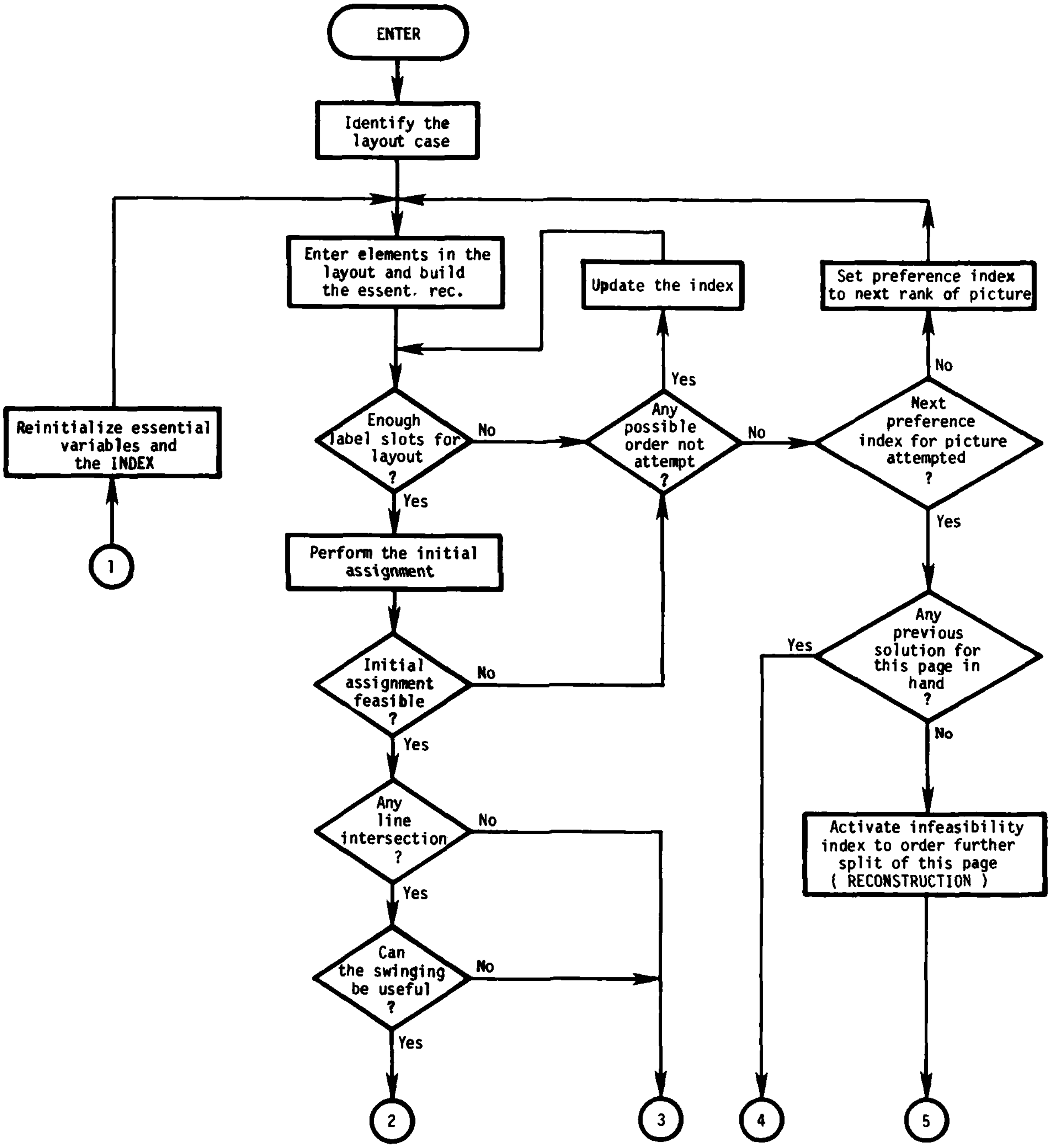
The MTDA Procedure Steps

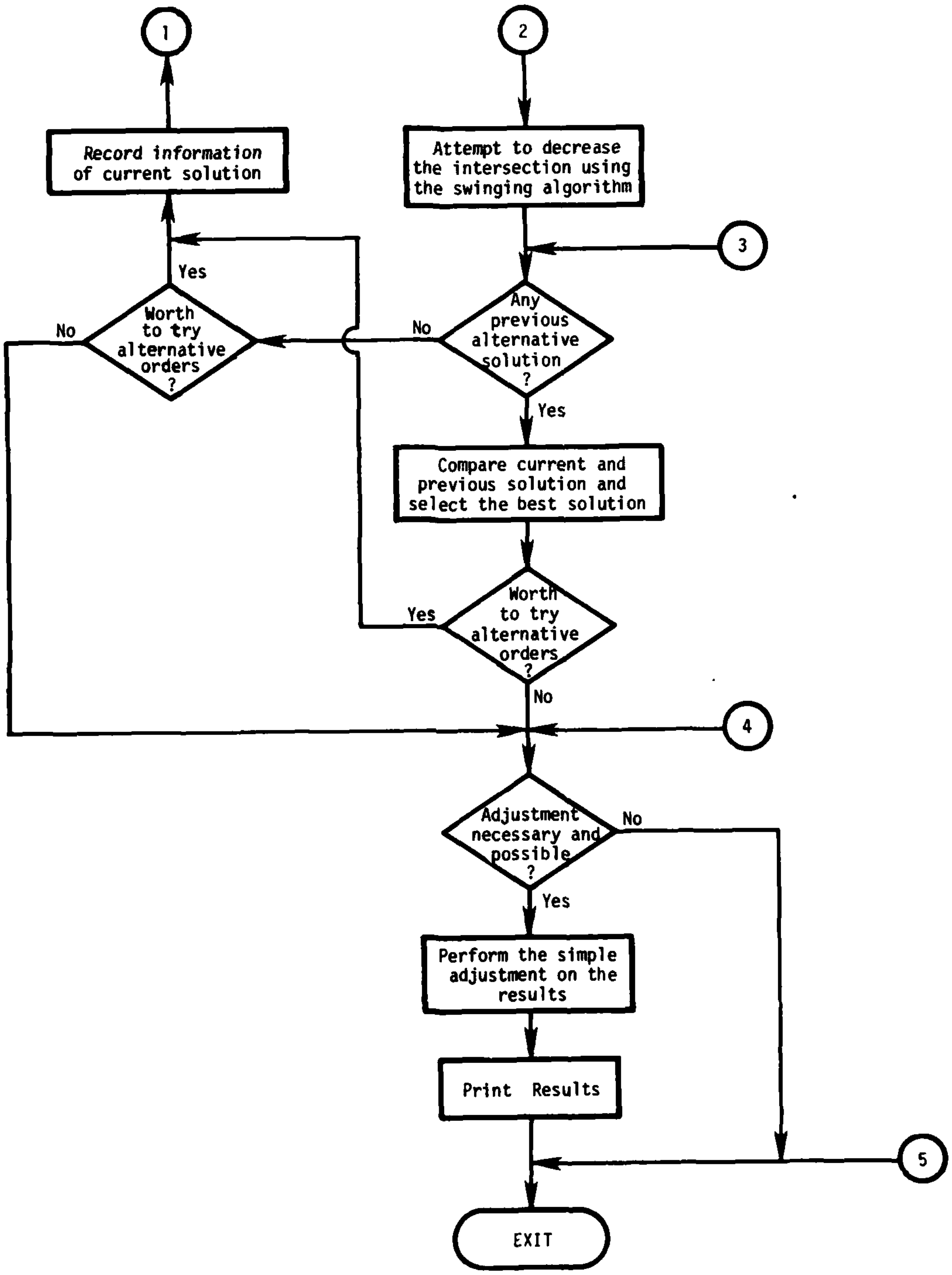



4
$\ell \in LZ_i$ ?
3
Yes
Get $\overline{K} = \overline{SVD}_i(\ell)$
2
$ALT_i(\overline{k}) \neq ALT_i(t)$ ?
Yes
No
Set $X_{i\ell} = 1$, $X_{ij} = 0$
$X_{t\ell} = 0$, $X_{tj} = 0$
Compare all pairs and evaluate new NX
$NX > NX_0$ ?
No
Perform the following updatings: IOLD(1) = [illegible] IOLD(2) = [illegible], MINT
Yes
3
Set $X_{ij} = 1$, $X_{i\ell} = 0$
$X_{t\ell} = 1$, $X_{tj} = 0$
Current solution is a MIDA
EXIT

The MIDA Procedure Steps (END)

The Page Layout Central Routine (MAAP)


ENTER
Identify the layout case
Enter elements in the layout and build the essent. rec.
Update the index
Set preference index to next rank of picture
Reinitialize essential variables and the INDEX
Enough label slots for layout ?
No
Yes
Any possible order not attempt ?
Yes
No
Next preference index for picture attempted ?
No
Yes
1
Perform the initial assignment
Initial assignment feasible ?
No
Yes
Any previous solution for this page in hand ?
Yes
No
Any line intersection ?
No
Yes
Activate infeasibility index to order further split of this page ( RECONSTRUCTION )
Can the swinging be useful ?
No
Yes
2
3
4
5


1
2
Record information of current solution
Attempt to decrease the intersection using the swinging algorithm
3
Yes
No
Worth to try alternative orders ?
No
Any previous alternative solution ?
Yes
Compare current and previous solution and select the best solution
Yes
Worth to try alternative orders ?
No
4
Adjustment necessary and possible ?
No
Yes
Perform the simple adjustment on the results
Print Results
5
EXIT

The Page Layout Central Routine (MAAP)

## APPENDIX C3

Sorted Distance Indices of the Illustrative Example

Values of $\overline{SVD}_i$ and $SVD_i (i=1,7)$

for the illustrative example (Figure 24)

$\overline{SVD}_1$ = [19, 20, 1, 18, 15, 2, 3, 17, 4, 16, 5, 14, 6, 7, 9, 10, 8, 11, 12]

$\overline{SVD}_2$ = [15, 14, 16, 13, 17, 12, 18, 19, 20, 11, 10, 9, 1, 4, 5, 3, 2, 6, 8, 7]

$\overline{SVD}_3$ = [ 4, 3, 5, 2, 1, 6, 20, 19, 7, 18, 8, 9, 15, 17, 10, 14, 16, 11, 13, 12]

$\overline{SVD}_4$ = [4, 5, 3, 6, 2, 7, 10, 19, 20, 8, 1, 9, 14, 15, 11, 13, 16, 18, 12, 17]

$\overline{SVD}_5$ = [9, 10, 8, 5, 6, 4, 7, 11, 3, 12, 2, 13, 14, 15, 1, 16, 17, 20, 19, 18]

$\overline{SVD}_6$ = [14, 13, 15, 12, 7, 16, 10, 9, 11, 17, 8, 18, 19, 5, 4, 6, 20, 3, 1, 2]

$\overline{SVD}_7$ = [16, 15, 14, 17, 19, 18, 13, 20, 1, 11, 2, 5, 3, 10, 4, 9, 6, 8, 12, 7]

$SVD_1$ = [3, 16, 4, 15, 2, 17, 19, 20, 5, 1, 14, 18, 6, 13, 7, 12, 8, 9, 10, 11]

$SVD_2$ = [15, 14, 16, 13, 17, 12, 4, 18, 3, 5, 19, 11, 2, 6, 10, 7, 20, 1, 9, 8]

$SVD_3$ = [4, 3, 6, 5, 2, 1, 20, 7, 15, 19, 16, 14, 17, 13, 8, 18, 9, 12, 10, 11]

$SVD_4$ = [4, 5, 3, 6, 14, 15, 7, 13, 2, 16, 17, 12, 1, 9, 8, 10, 20, 19, 11, 18]

$SVD_5$ = [5, 6, 4, 7, 13, 9, 10, 12, 15, 11, 16, 2, 17, 1, 20, 18]

$SVD_6$ = [14, 13, 15, 12, 16, 7, 11, 10, 17, 5, 4, 6, 9, 18, 8, 19, 2, 3, 20, 1]

$SVD_7$ = [16, 15, 12, 14, 17, 13, 18, 19, 5, 20, 3, 4, 2, 1, 6, 11, 10, 7, 9, 8]

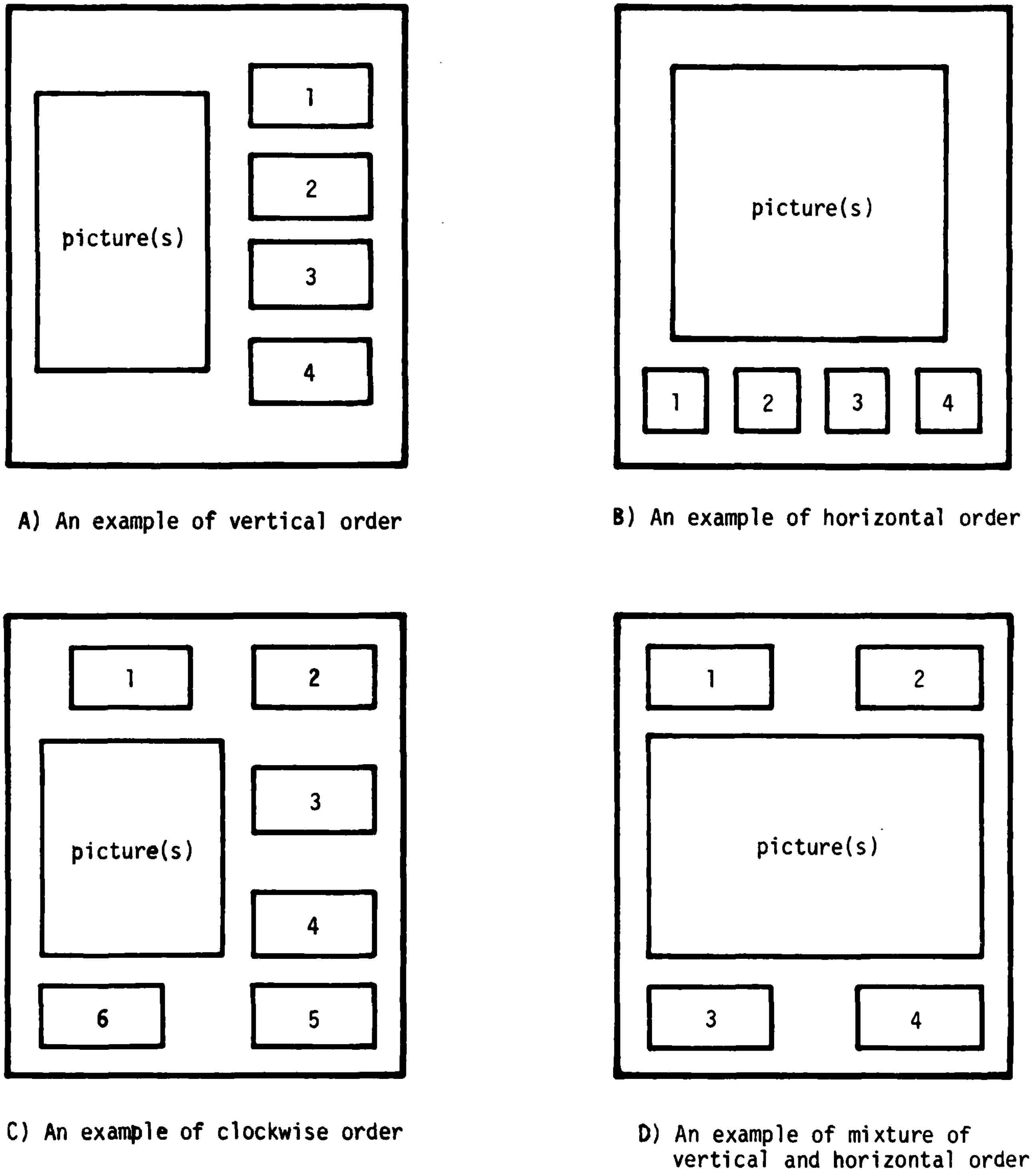
# APPENDIX D1

## The Questions and The Alternatives Responses Offered

1. Four arrangements of labels around figures are used frequently: vertical, horizontal, clockwise and mixed as shown in Figure D1 Please rank order these in term of desirability (eg. C, A, D, B)

BEST □ □ □ □ WORST

Your Comments:



A) An example of vertical order

B) An example of horizontal order

C) An example of clockwise order

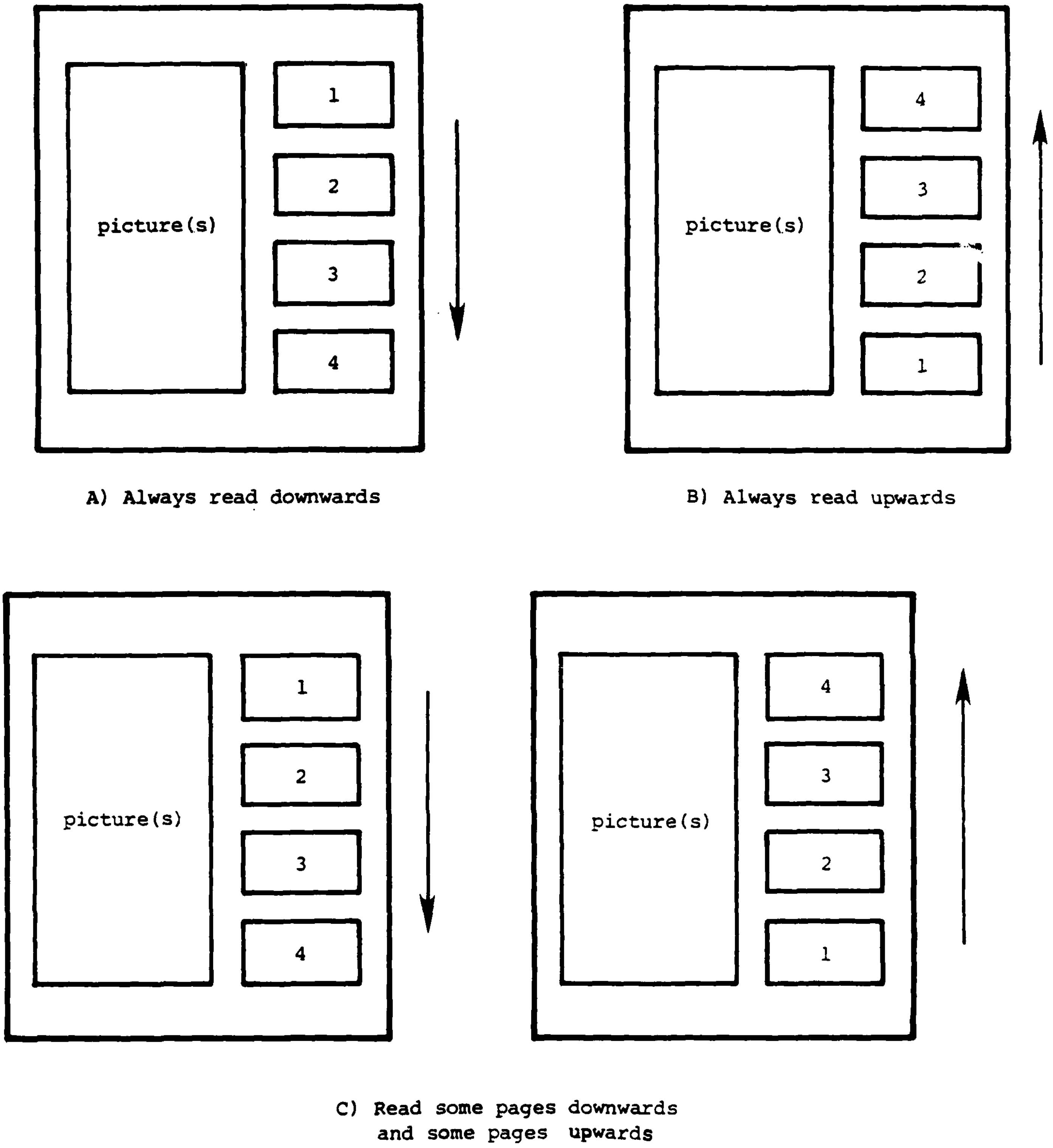
D) An example of mixture of
vertical and horizontal order

Figure D1. Illustration of alternative orderings of the labels.

2. For a Vertical layout of the labels (A of Figure D1) there are three logical directions in which the labels can be ordered, shown in Figure D2. Please rank order these in terms of their desirability (eg. B, C, A).

BEST □ □ □ WORST

Your Comments:



A) Always read downwards

B) Always read upwards

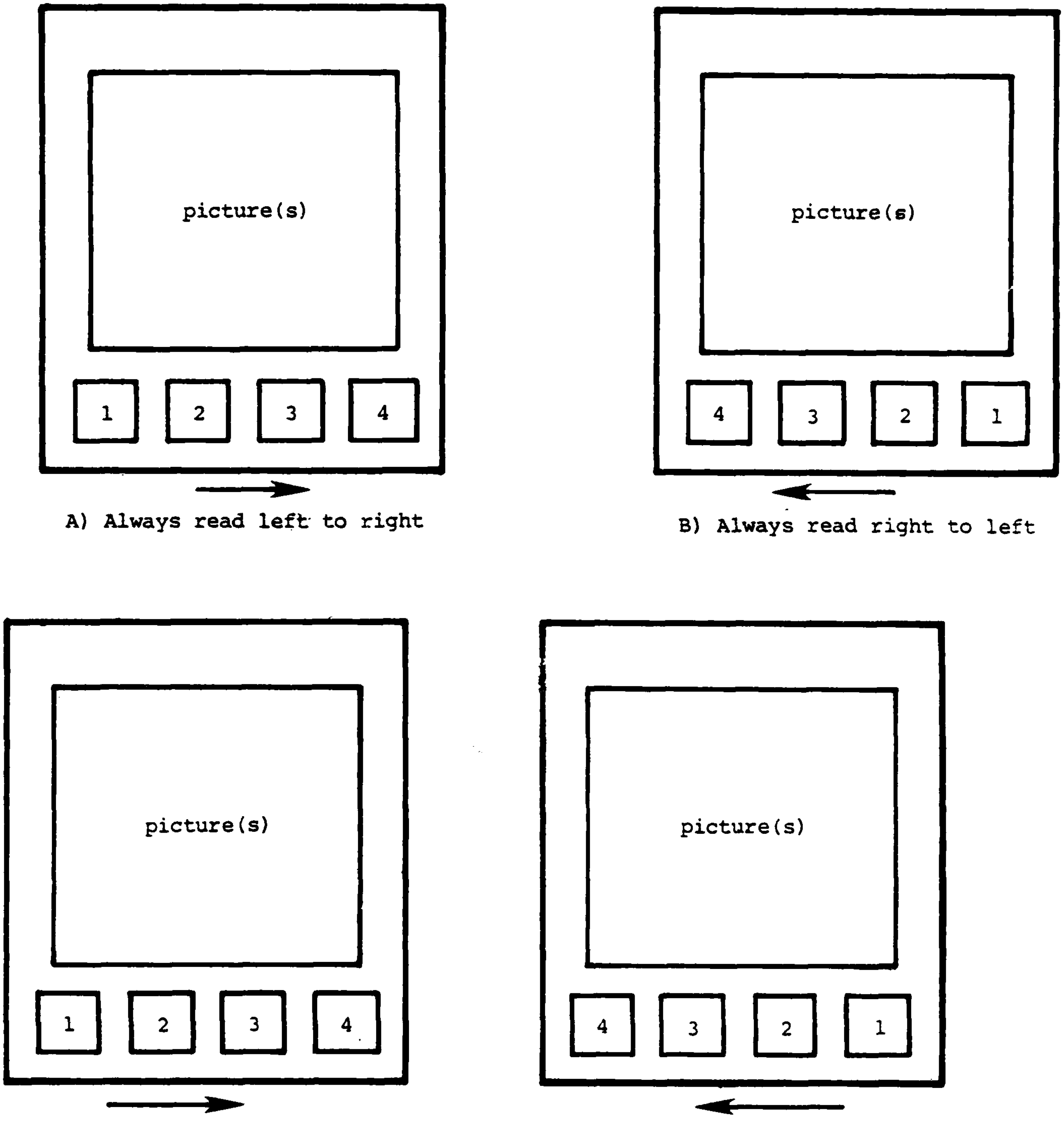
C) Read some pages downwards
and some pages upwards

Figure D2. Illustration of alternative vertical orders.

3. For a horizontal layout of the labels (B of Figure D1) there are three logical directions in which the labels can be ordered, shown in Figure D3. Please rank order these in terms of their desirability (eg. B, C, A).

BEST □ □ □ WORST

Your Comments:



A) Always read left to right

B) Always read right to left

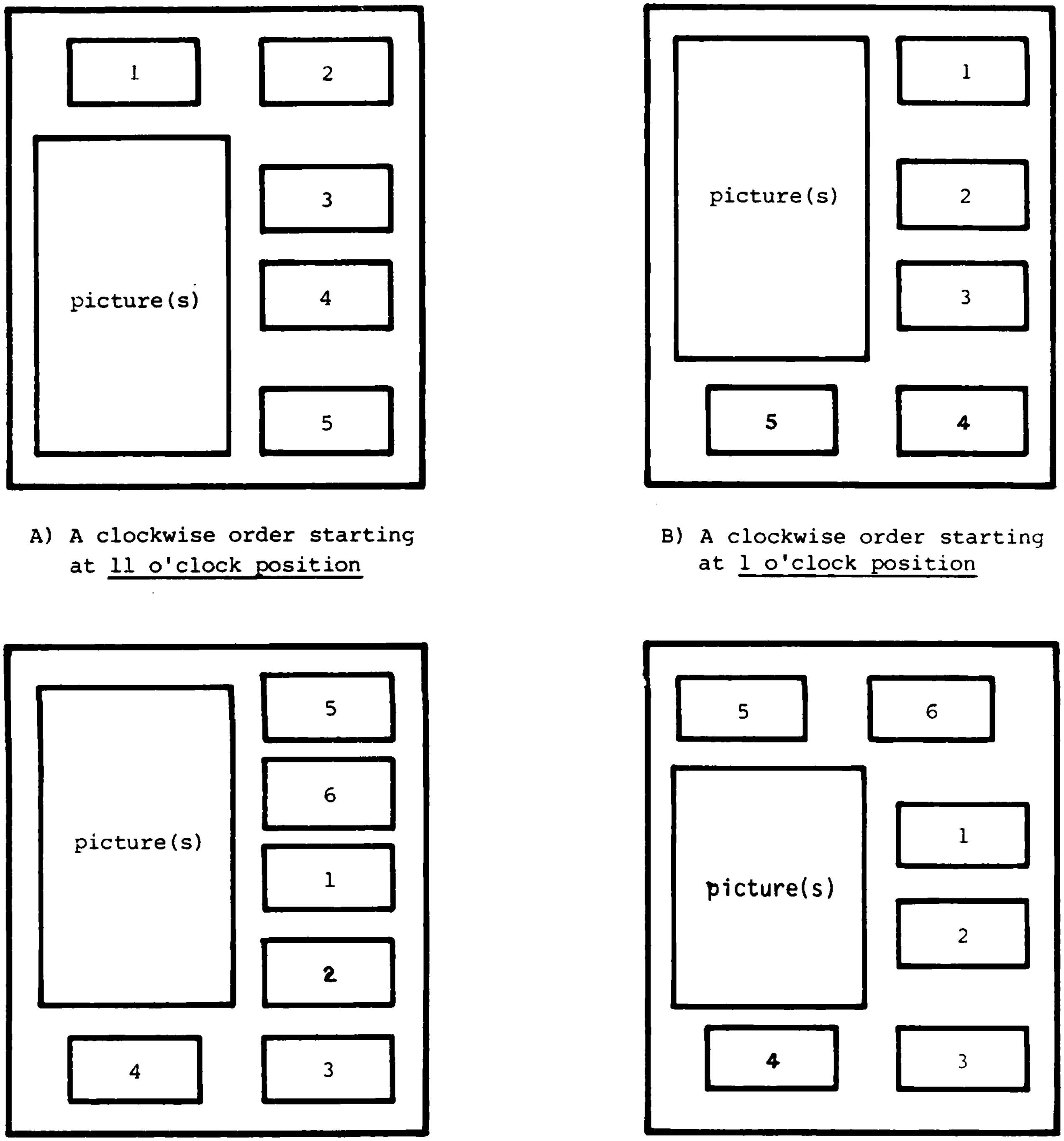
C) Read some pages left to right and
read some pages right to left

Figure D3. Illustration of alternative horizontal order.

4. For a clockwise layout of the labels (C of Figure D1) there are **four** logical directions in which the labels can be ordered shown in Figure D4. Please rank order these in terms of their desirability (eg. **C, A, B, D**).

| | | | | | |
|---|---|---|---|---|---|
| BEST | | | | | WORST |

Your Comments:



A) A clockwise order starting at 11 o'clock position

B) A clockwise order starting at 1 o'clock position

C) A clockwise order starting at 3 o'clock position

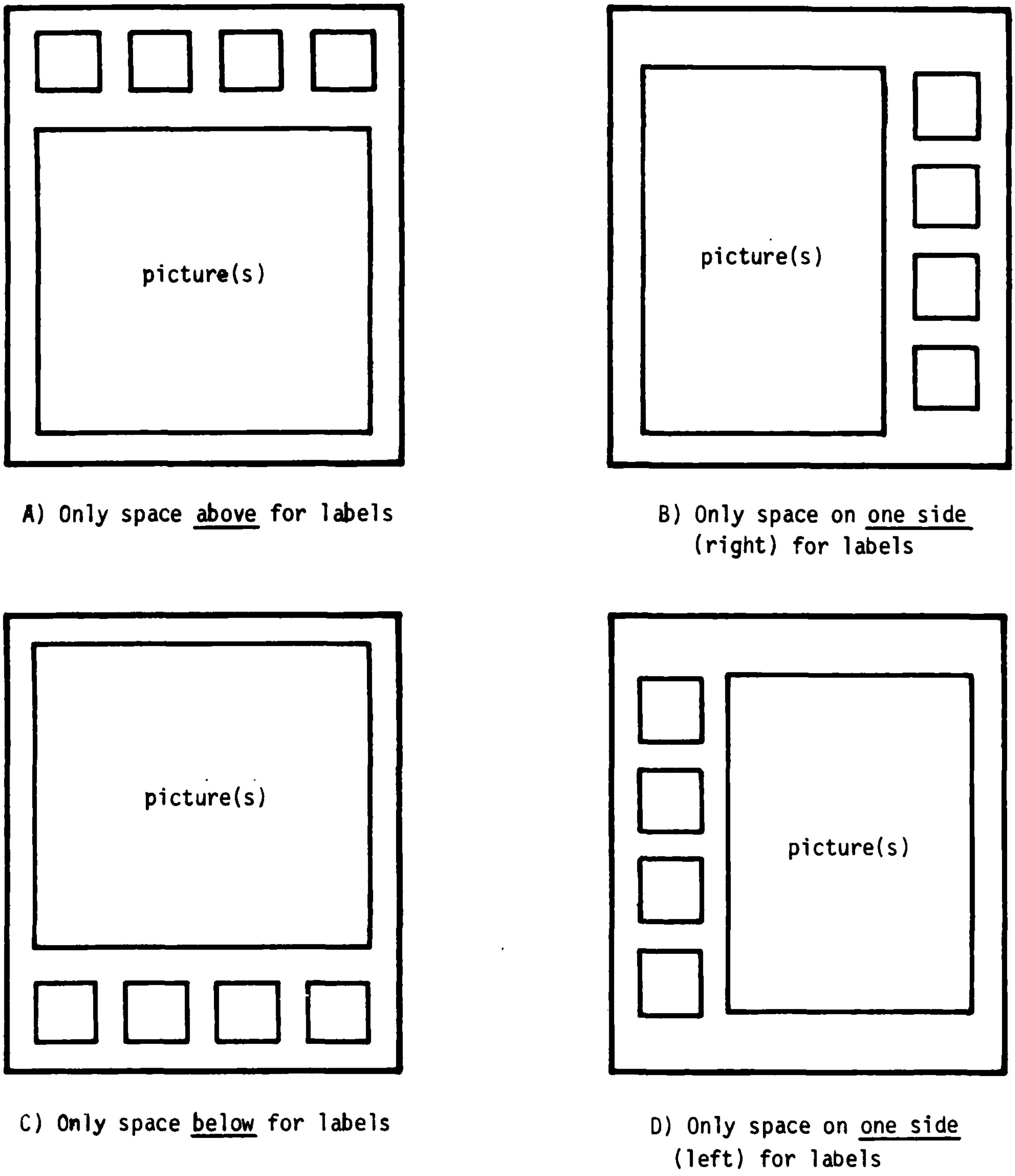
D) A clockwise order starting at any position with the label marked darker

Figure D4. Illustration of alternative clockwise orders.

5. If a page has sufficient space for labels along one side only, four possibilities exist as shown in Figure D5. Please rank order these in terms of desirability (e g. A, C, D, B).

| | | | | | |
|---|---|---|---|---|---|
| BEST | | | | | WORST |

Your Comments:



A) Only space above for labels

B) Only space on one side (right) for labels

C) Only space below for labels

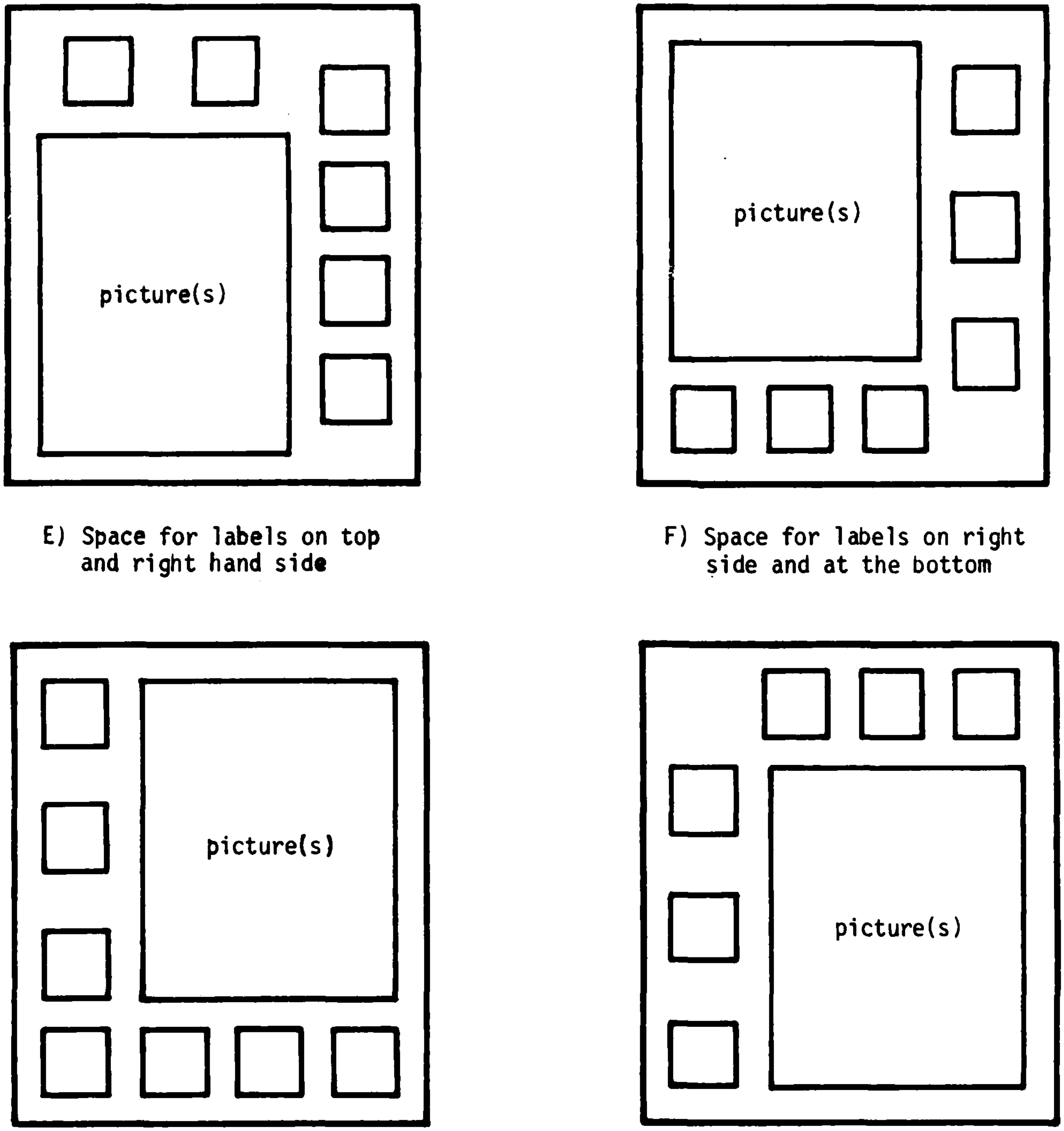
D) Only space on one side (left) for labels

Figure D5. Illustration of alternative ways to have labels in the case of space limitation of question 5.

6. If a page has sufficient space for labels along two sides only, four possibilities exist as shown in Figure D6. Please rank order these in terms of desirability (eg. F, E, H, G).

BEST □ □ □ □ WORST

Your Comments:



E) Space for labels on top and right hand side

F) Space for labels on right side and at the bottom

G) Space for labels at the bottom and on right hand side

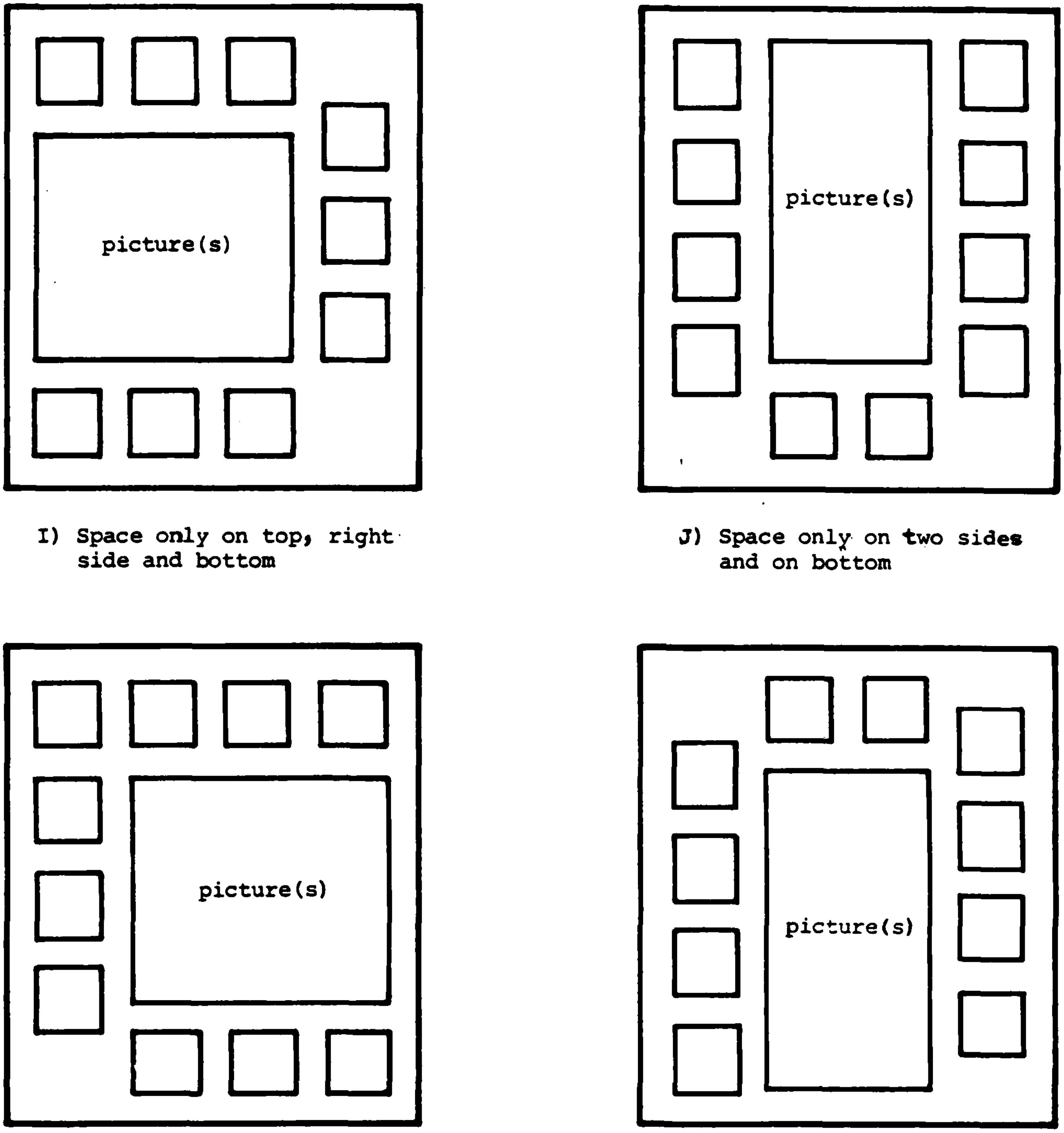
H) Space for labels on right hand side and on the top

Figure D6. Illustration of alternative ways to have labels in the case of space limitation of question 6.

7. If a page has sufficient space for labels along three sides only, four possibilities exist as shown in Figure D7. Please rank order these in terms of desirability (eg. J, I, L, K).

| | | | | | |
|---|---|---|---|---|---|
| BEST | | | | | WORST |

Your Comments:



I) Space only on top, right side and bottom

J) Space only on two sides and on bottom

K) Space only on top, bottom and left hand side

L) Space on two sides and on top

**Figure D7.** Illustration of alternative ways to have labels in the case of space limitation of question 7.

8. Going back over questions 5, 6 and 7 please take the best two alternatives from each question and rank order all six in terms of their desirability (eg. A, F, J, C, I, E).

BEST □ □ □ □ □ □ WORST

Your Comments:

9. If, despite your efforts to place all related material on one page, it becomes necessary to duplicate pictures or labels, there are four possibilities:

A) Limit the duplication to the labels only,

B) Limit the duplication to the pictures only,

C) Duplicate both the picture(s) and the label(s) as it becomes necessary to do so, but give notice about the duplication where it takes place,

D) Absolutely do not use a duplication of any kind.

Please rank order these four alternatives in terms of their desirability (eg. A, B, D, C)

BEST □ □ □ □ WORST

Your Comments:

10. Pictures can be of various sizes, is it important to keep all pictures the same size?

□ Important

□ Not Important

Your **Comments**:

11. In Figure D8, a typical page, we have arrows from pictures to pictures and arrows from pictures to labels. In deciding where to place labels and pictures, keeping arrows short is important. There are three alternatives:

A. Picture to Picture arrows are more important.

B. Picture to label arrows are more important.

C. Both types of arrows are equal in importance.

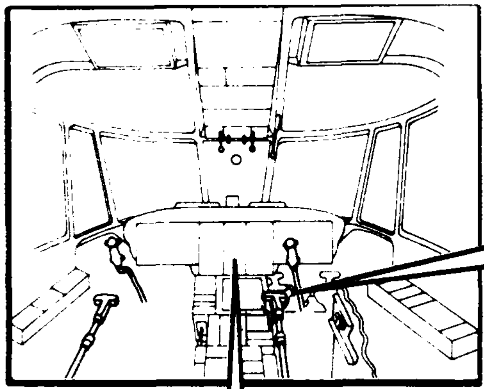
Please rank order these alternatives (eg. A, B, C)

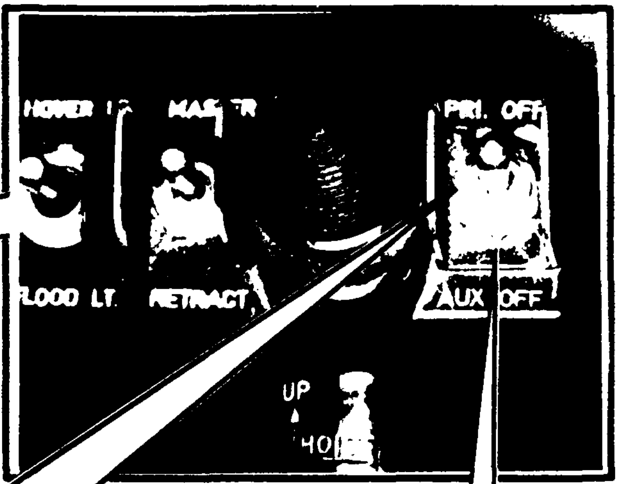
| | | | | |
|---|---|---|---|---|
| BEST | | | | WORST |

Your Comments:

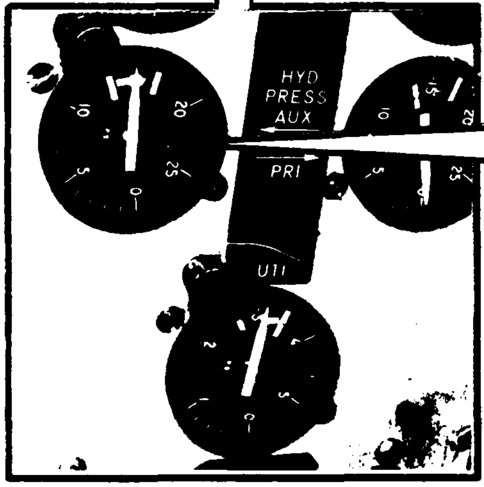
32. Servo Sensor .... CHECK

To insure proper operation of the primary servo 1000 PSI switch which prevents securing the AUX if PRI pressure is less than 1000 PSI. (IF BLADES ARE SPREAD)





8. Action
Place servo switch to AUX OFF (AFT)



9. Result
AUX HYD pressure should remain at normal range (1300 to 1600 PSI)

10. Note
IF AUX HYD pressure drops
THEN Primary servo 1000 PSI switch is defective. Aircraft is DOWN.

11. Action
Place servo switch to center position

**GO TO PAPER MOCK-UP**

- Step through all items
- Touch where each action and response takes place
- Recall exact action for each item

Figure D8. An example of a typical page layout showing pictures, labels, and arrows

12. Label size can vary, just as picture size can. There are three alternatives here:

A. All labels on a page should be the same size, based on the maximum size needed on that page.

B. All labels in a procedure should be the same size, based on the maximum size needed in that procedure.

C. A pre-specified standard size should be used and the wording in a label modified to fit the pre-specified label size.

Please rank order these alternatives (eg. A, C, B)

BEST □ □ □ □ WORST

Your Comments:

13. Usually a page will contain an overview picture linked to other pictures which are in turn linked to labels, for example see Figure D8. The position of the overview picture can be important in page layout.

(a). If there are only two pictures on a page, then the four alternatives shown in Figure D9 are possible. For each alternative please put an asterisk (*) in which location you will prefer to have the overview picture. Also rank order these four alternatives (eg. D, C, B, A)

| | | | | | |
|---|---|---|---|---|---|
| BEST | | | | | WORST |

Your Comments:

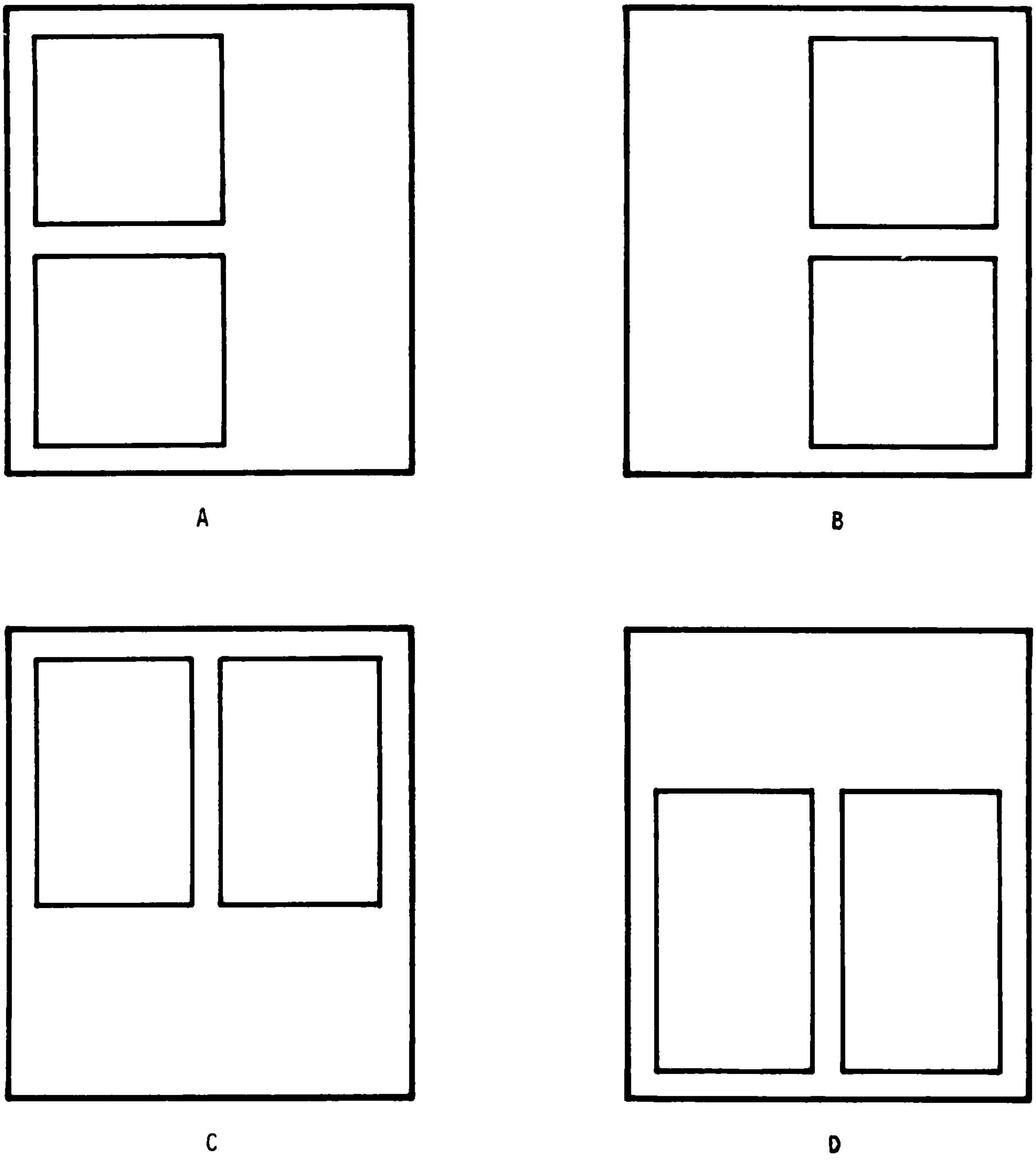


Figure D9. Illustration of alternative layout examples with three pictures on the page.

13. (b). If there are only three pictures on a page, then the four alternatives shown in Figure D10 are possible. For each alternative please put an asterisk (*) in which location you will prefer to have the overview picture. Also rank order these alternatives (eg. B, C, A, D)

| | | | | | |
|---|---|---|---|---|---|
| BEST | | | | | WORST |

Your Comments:

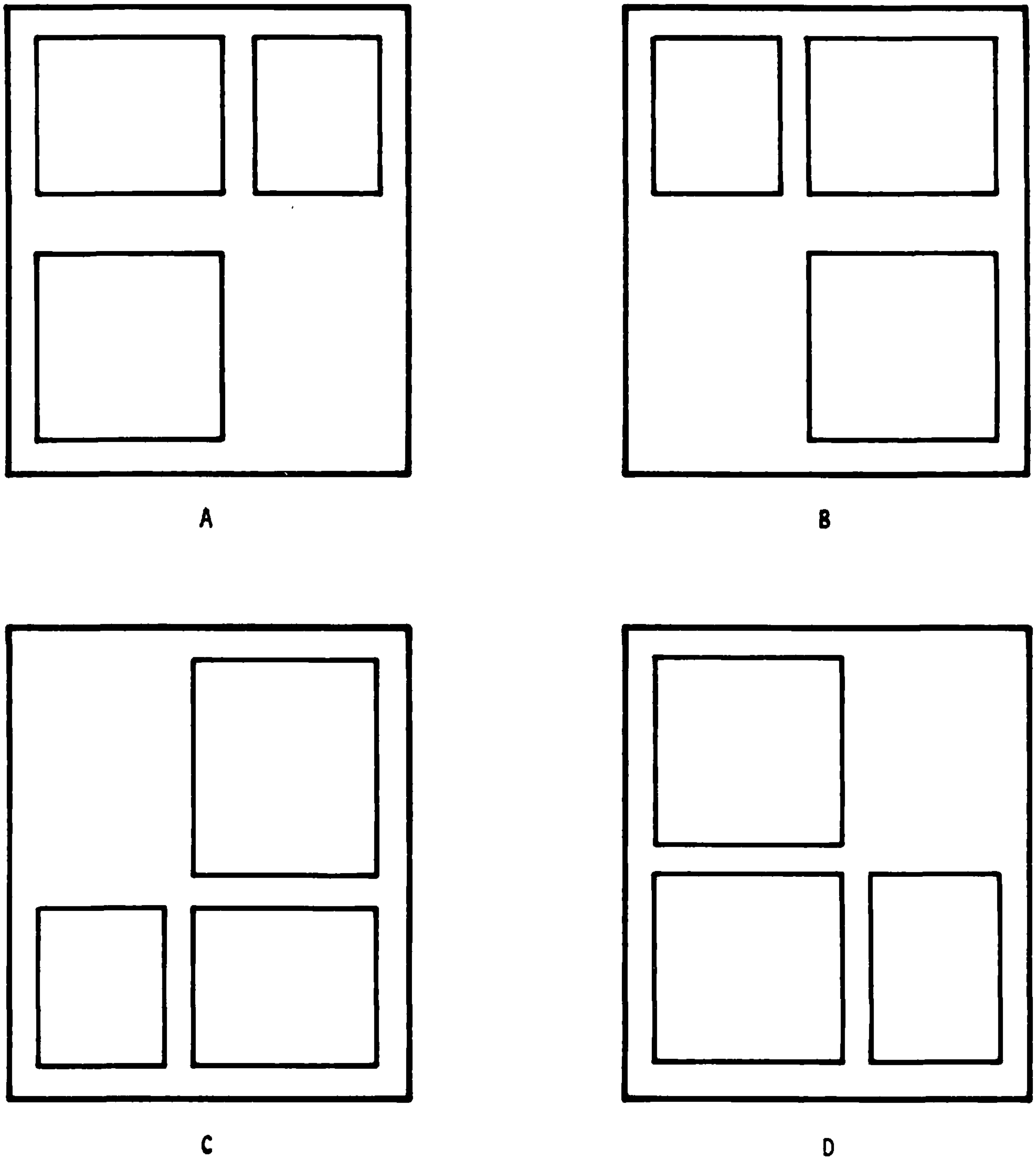


Figure D10. Illustration of alternative layout examples with two pictures on the page

13. (c). If there are only four pictures in a page, then the four alternatives shown in Figure D11 are possible. The asterisk identify the location of the overview picture for each alternative. Please rank order these alternatives (eg. D, C, A, B)

BEST □ □ □ □ WORST

Your Comments:

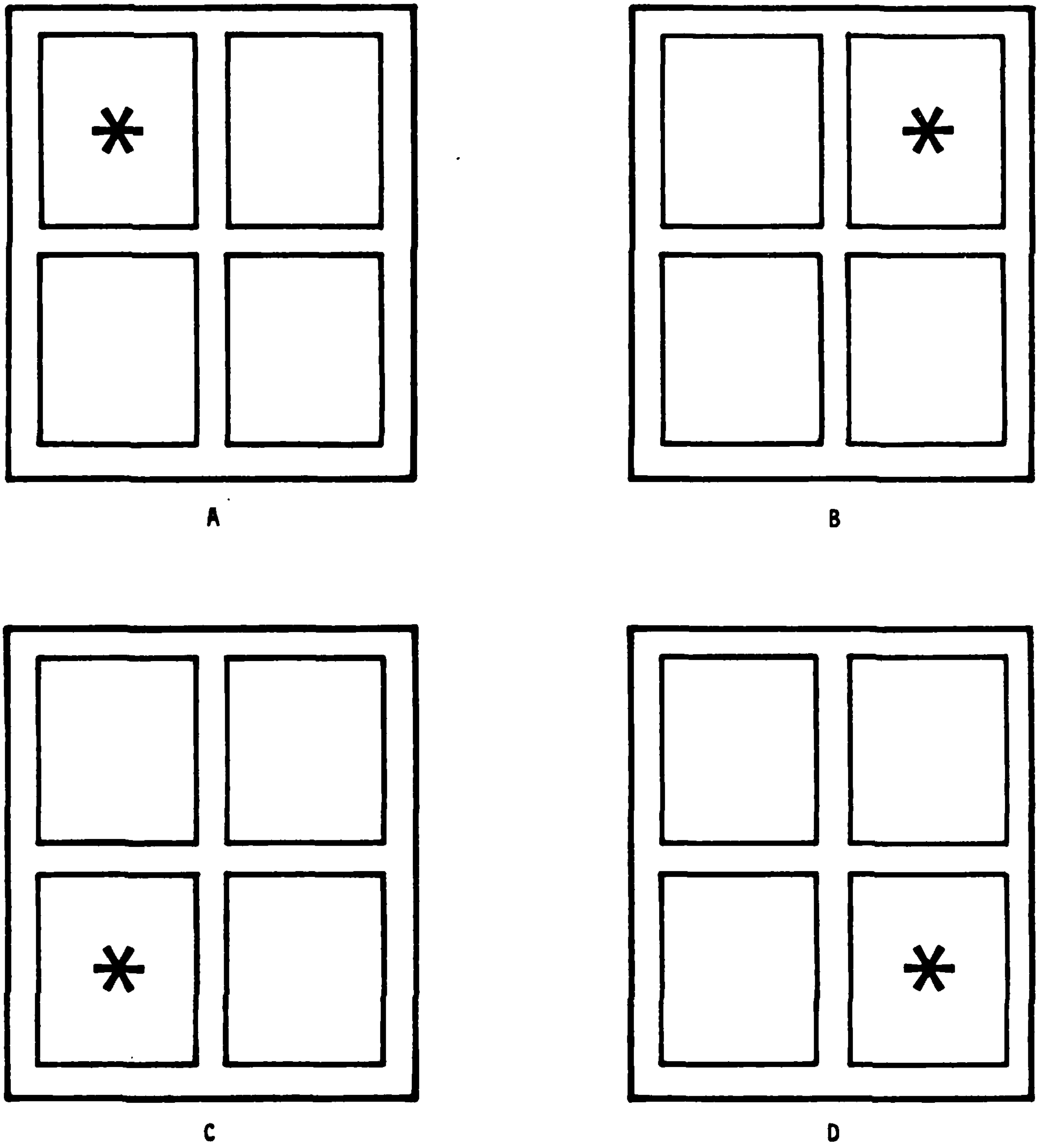


Figure D11. Illustration of alternative layout examples with four pictures on the page.

## APPENDIX D2

### Derivation of Friedman Test Results

To perform the Friedman test on the data of question 1 in Table 9, (this is actually valid for every other question except question 8 and 9), we first consider the alternatives ranked from best to worst and give for each row a rank of 1 to the most left side (best) alternative, give a rank of 2 to the adjacent (next lowest) alternative in each row, etc. By doing this we obtain the data shown in Table 10. Observe that the ranks in each subject row of Table 10 range from 1 to $k = 4$ .

Now if the null hypothesis (that all the samples - columns - came from the same population) is in fact true, then the distribution of ranks in each column would be a matter of chance, and thus we would expect the ranks of 1, 2, 3, and 4 to appear in all columns with about equal frequency. This would indicate that for any subject it is a matter of chance under which alternative the lowest rank occurs and under which alternative the highest rank occurs, which would be the case if all the alternatives in question 1 (actually any question) really did not differ. If the subjects' rankings were dependent on the alternatives (i.e., if Ho were false), then the rank totals would vary from one column to another. Inasmuch as the columns all contain an equal number of cases, an equivalent statement would be that under Ho the mean ranks of the various columns would be about equal.

The Friedman test determines whether the rank total ($R_j$) differs significantly. To make this test, we compute the value of a statistic which Friedman denotes as $X_r^2$ .

For a number row and/or column not too small, Friedman (1937) shows that $X_r^2$ is distributed approximately as chi square with $d_f = k - 1$ , when

$$X_r^2 = \frac{12}{Nk(k+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(k+1) \qquad (1)$$

where N = number of rows

k = number of columns

$R_j$ = sum of rank in $j^{th}$ column

$\sum_{j=1}^{k}$ = directs one to sum the squares of the sums of rank over all k alternatives.

To illustrate the computation of $X_r^2$ and show how the conclusion about Ho in Table 10, we can test for significance the data shown in question 1. The k = 4 (alternatives) rank sums values are 18, 39, 38 and 45. The number of subjects responses accounted is N = 12. We can compute the value of $X_r^2$ for the data of question 1 in Table 10 by substituting the values in formula (1):

$$X_r^2 = \frac{12}{Nk(k+1)} \sum_{j=A,B,C,D} (R_j)^2 - 3N(k+1)$$

$$= \frac{12}{14x4x5} [18^2 + 39^2 + 38^2 + 45^2] - 3x14x(5)$$

$$= 17.74$$

The probability of occurrence under Ho of $X_r^2 \geq 17.74$ for k = 4 and N = 14 is $p < 0.001$ . With these data, therefore, we could reject the null hypothesis that the four alternatives orders (A,B,C,D) proposed for question 1 have equal preference with respect to mean rank at less than .001 level of significance.

# APPENDIX D3

## Results From Test 2 When Test 1 Concludes With The Absence of An Overall Similarity Between Alternatives

### Group 1

### Question 1

|  | B | C | D |  |
|---|---|---|---|---|
| Rank Sum | 21 | 20 | 27 | A |
| Differences |  | 1 | 6 | B |
|  |  |  | 7 | C |

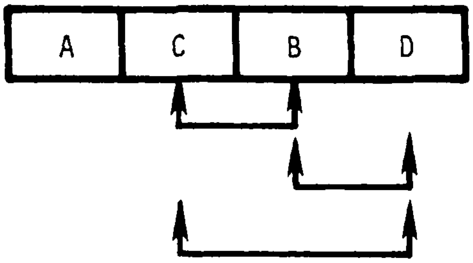
Number of alternatives k = 4

Number of subjects N = 14

Number of comparisons p = 6

Critical value at
20% = 14.53
10% = 16.35
5% = 18.02

Ranking and Relationships

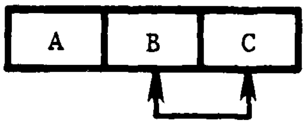


### Question 2

|  | B | C |  |
|---|---|---|---|
|  | 18.5 | 23.5 | A |
|  |  | 5 | B |

$$K = 3,\ N = 14,\ P = 3,\ \text{critical value at} \begin{cases} 20\% = 9.70 \\ 10\% = 11.26 \\ 5\% = 12.67 \end{cases}$$

Ranking and Relationships:

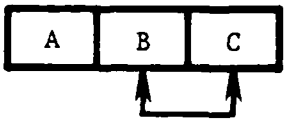


Question 3

| | B | C |
|---|---|---|
| A | 17.5 | 24.5 |
| B | | 7 |

$$K = 3,\ N = 14,\ P = 3,\ \text{critical value at} \begin{cases} 20\% = 9.70 \\ 10\% = 11.26 \\ 5\% = 12.67 \end{cases}$$

Ranking and Relationships:

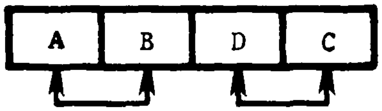


Question 4

| | B | C | D |
|---|---|---|---|
| A | 6 | 32 | 26 |
| B | | 26 | 20 |
| C | | | 6 |

$$K = 4,\ N = 14,\ P = 6,\ \text{critical value at} \begin{cases} 20\% = 14.53 \\ 10\% = 16.35 \\ 5\% = 18.02 \end{cases}$$

Ranking and Relationships:



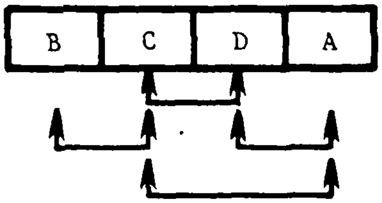
## Group 2

### Question 5

| B | C | D | |
|---|---|---|---|
| 33 | 17 | 14 | A |
| | 16 | 19 | B |
| | | 3 | C |

$$K = 4,\ N = 14,\ P = 6, \text{ critical value at } \begin{cases} 20\% = 14.53 \\ 10\% = 16.35 \\ 5\% = 18.02 \end{cases}$$

Ranking and Relationships:

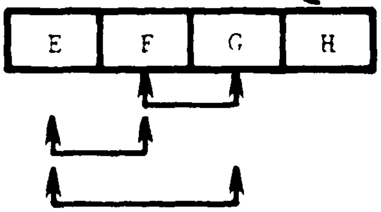


### Question 6

| F | G | H | |
|---|---|---|---|
| 7 | 10 | 31 | E |
| | 3 | 24 | F |
| | | 21 | G |

$$K = 4,\ N = 14,\ P = 6, \text{ critical value at } \begin{cases} 20\% = 14.53 \\ 10\% = 16.35 \\ 5\% = 18.02 \end{cases}$$

Ranking and Relationships:

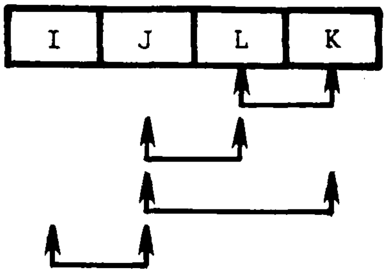


Question 7

| | J | K | L |
|---|---|---|---|
| I | 14.5 | 25 | 26.5 |
| J | | 10.5 | 12 |
| K | | | 1.5 |

K = 4, N = 14, P = 6, critical value at
20% = 14.53
10% = 16.35
5% = 18.02

Ranking and Relationships:



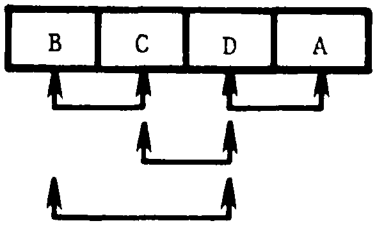
Group 3

Question 9

| | A | C | D |
|---|---|---|---|
| A | 19 | 16.5 | 6.5 |
| B | | 2.5 | 12.5 |
| C | | | 10 |

K = 4, N = 14, P = 6, critical value at
20% = 14.53
10% = 16.35
5% = 18.02

Ranking and Relationships:



Question 12: All alternatives are similarly preferred

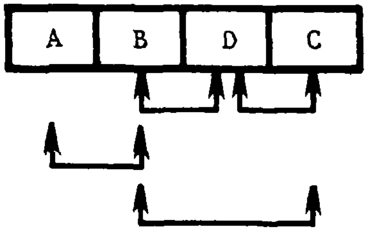
Group 4

Question 13a

| B | C | D | |
|---|---|---|---|
| 12.5 | 27.5 | 20 | A |
| | 17.5 | 7.5 | B |
| | | 7.5 | C |

K = 4, N = 14, P = 6, critical value at
20% = 14.53
10% = 16.35
5% = 18.02

Ranking and Relationships:

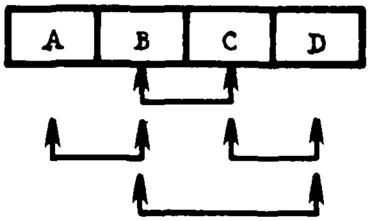


Question 13b

| B | C | D | |
|---|---|---|---|
| 13 | 18.5 | 28.5 | A |
| | 5.5 | 15.5 | B |
| | | 10 | C |

K = 4, N = 14, P = 6, critical value at
20% = 14.53
10% = 16.35
5% = 18.02

Ranking and Relationships:

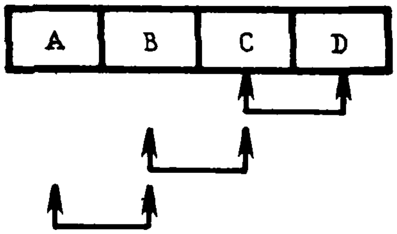


Question 13c

| | B | C | D |
|---|---|---|---|
| A | 15 | 26.5 | 35.5 |
| B | | 11.5 | 20.5 |
| C | | | 9 |

$$K = 4,\ N = 14,\ P = 6,\ \text{critical value at} \begin{cases} 20\% = 14.53 \\ 10\% = 16.35 \\ 5\% = 18.02 \end{cases}$$

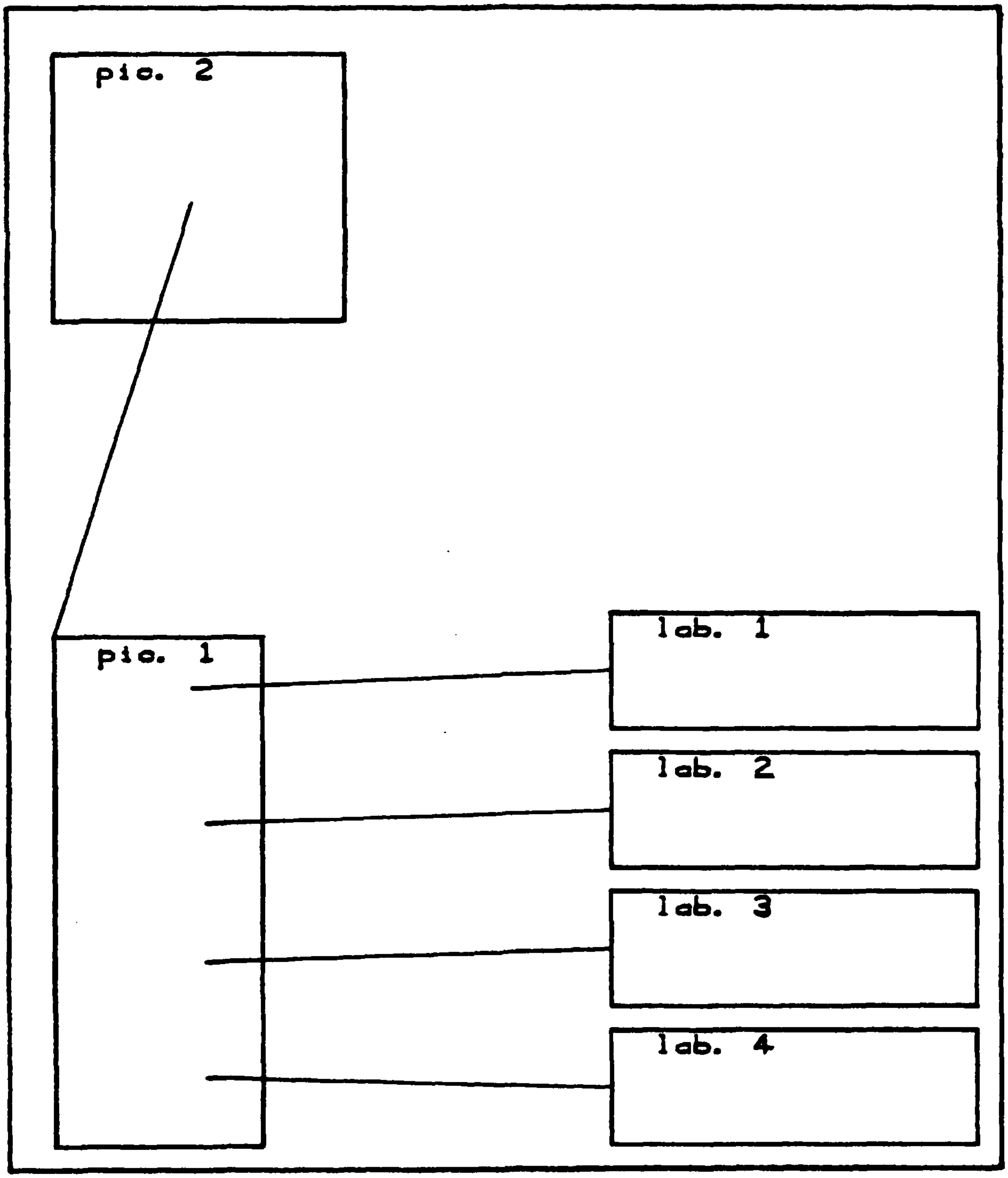
Ranking and Relationships:

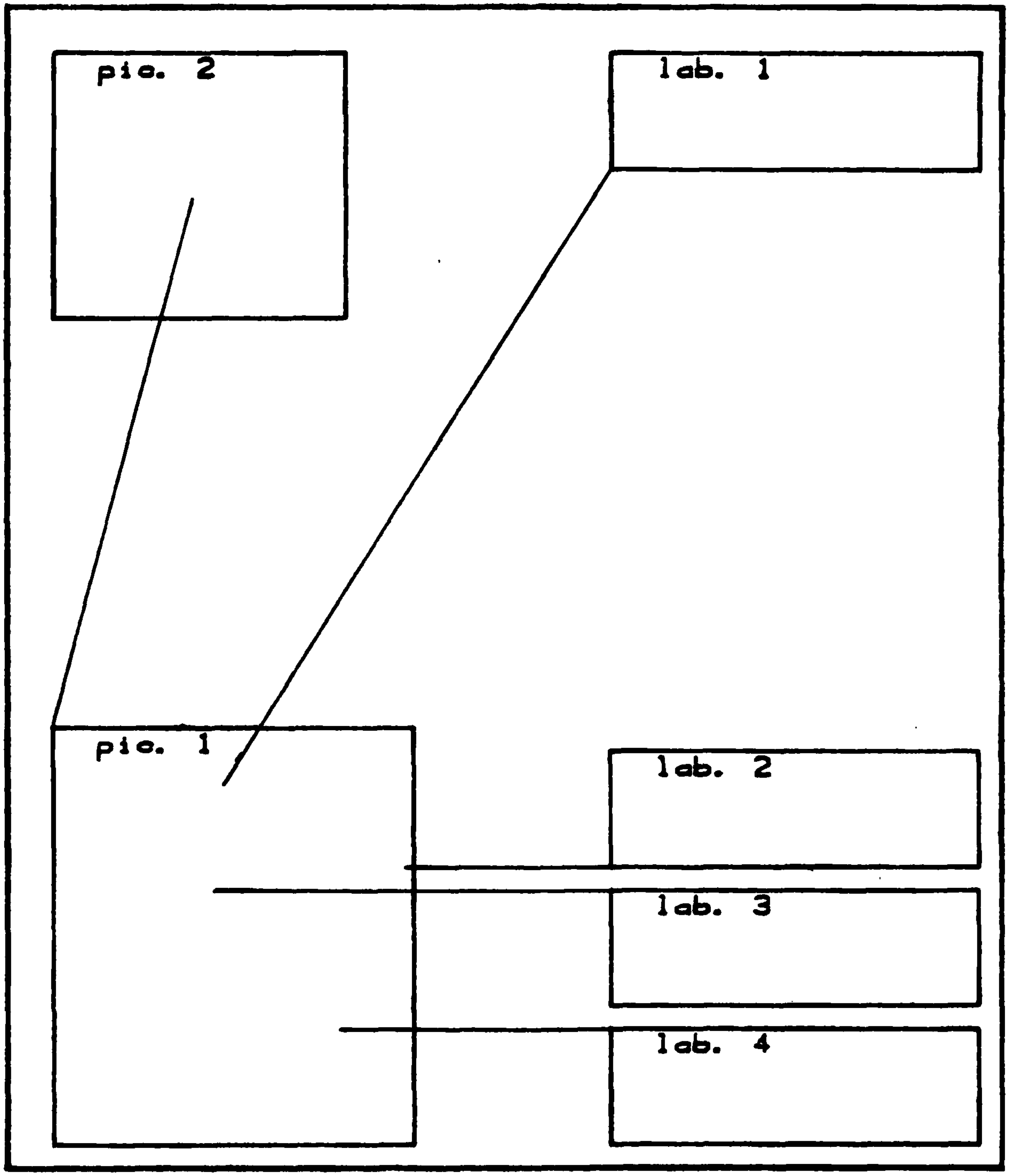


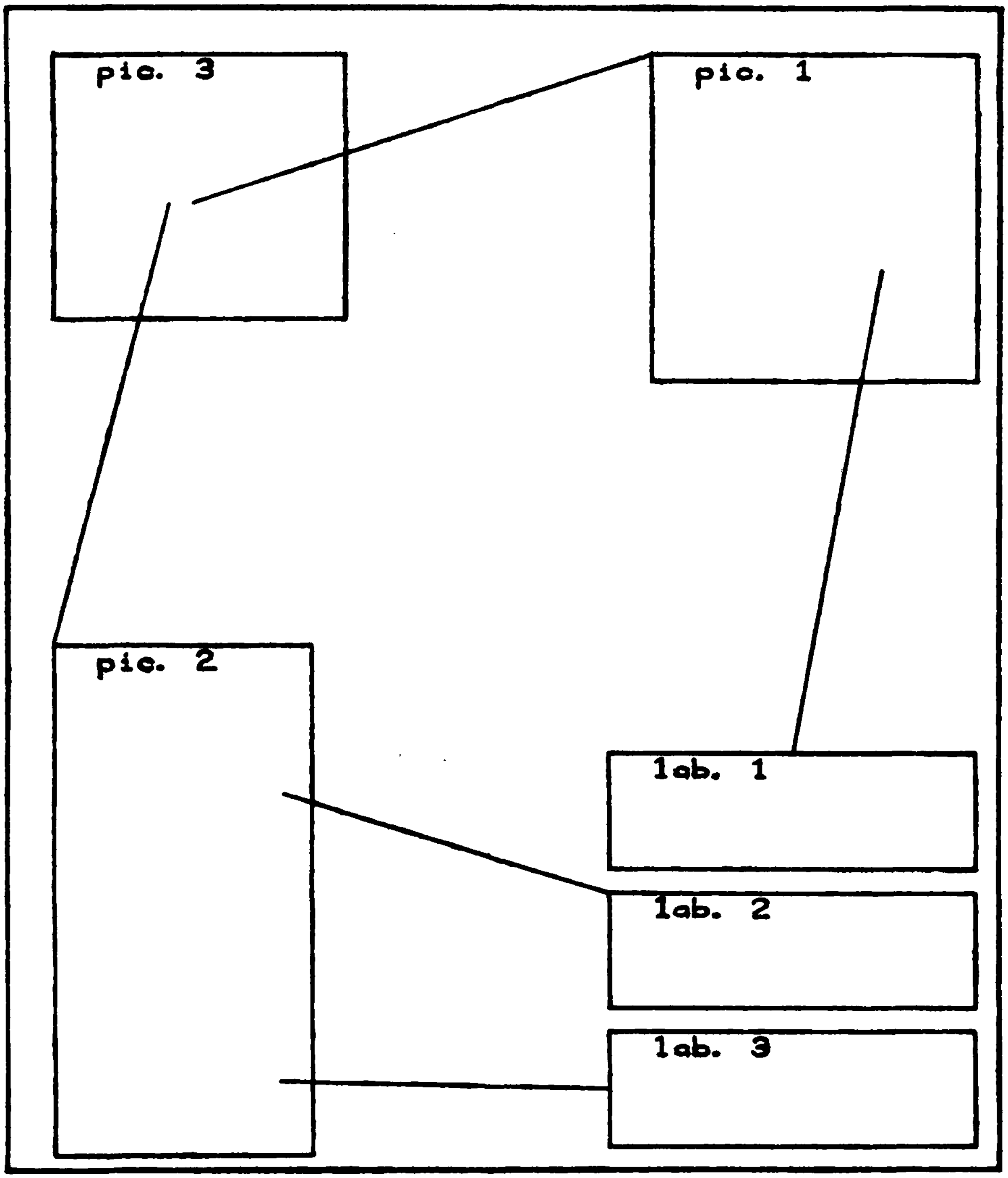
## APPENDIX E

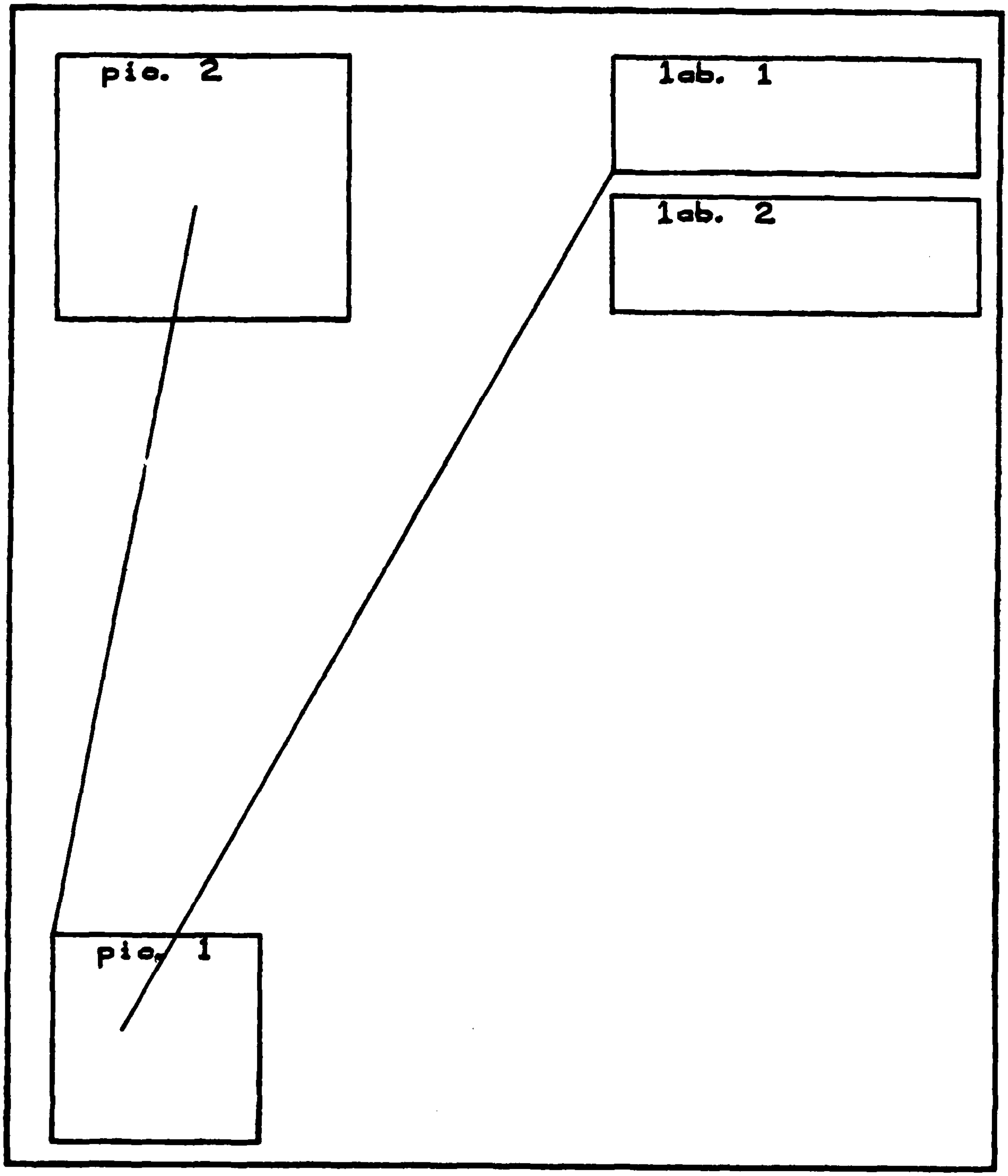
Result Plots of the 13 Task Steps Procedure

(Note: The current figures are reduced to 74%
of their real sizes).


pic. 2
pic. 1
lab. 1
lab. 2
lab. 3
lab. 4


pic. 2
lab. 1
pic. 1
lab. 2
lab. 3
lab. 4


pic. 3
pic. 1
pic. 2
lab. 1
lab. 2
lab. 3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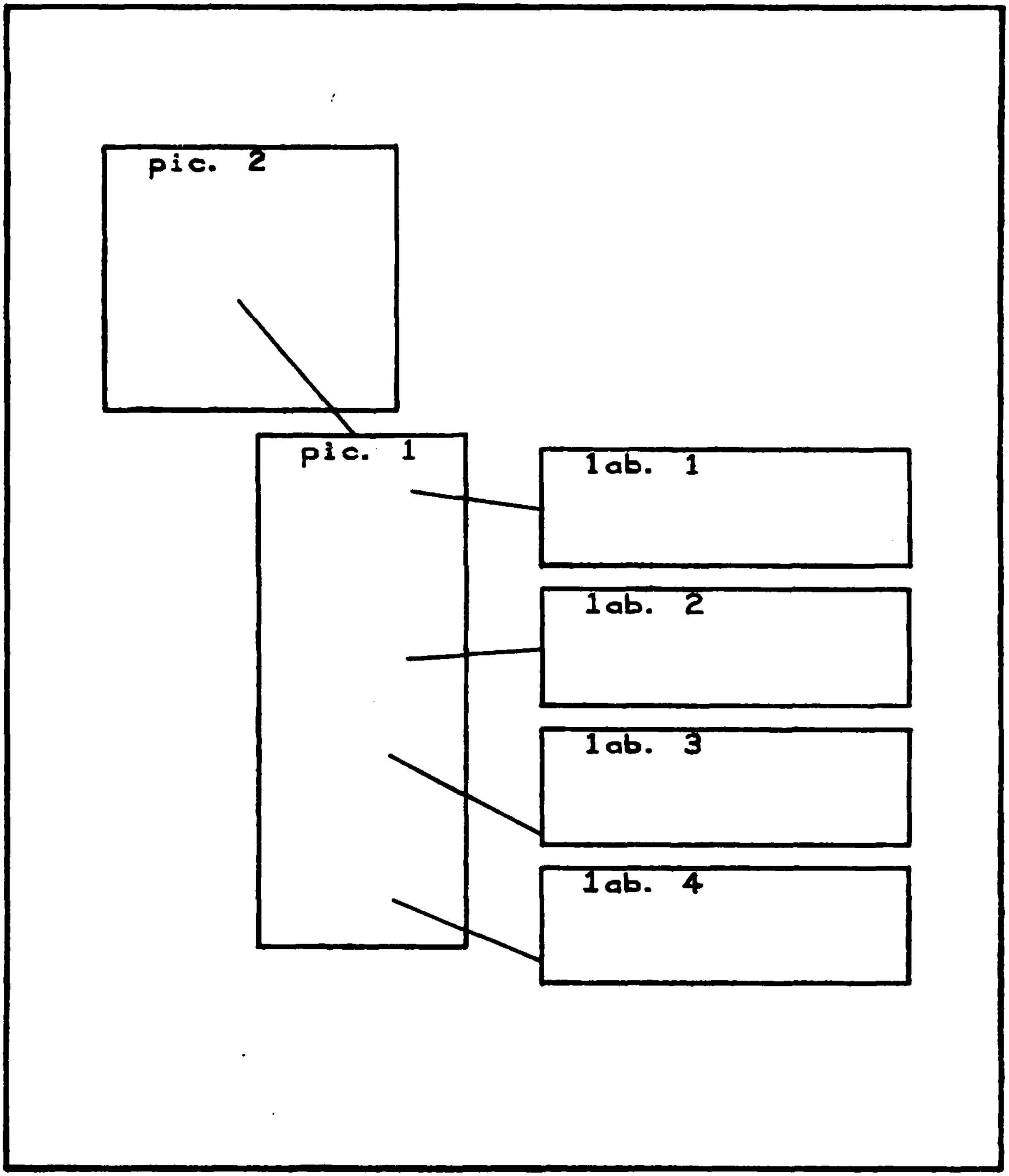
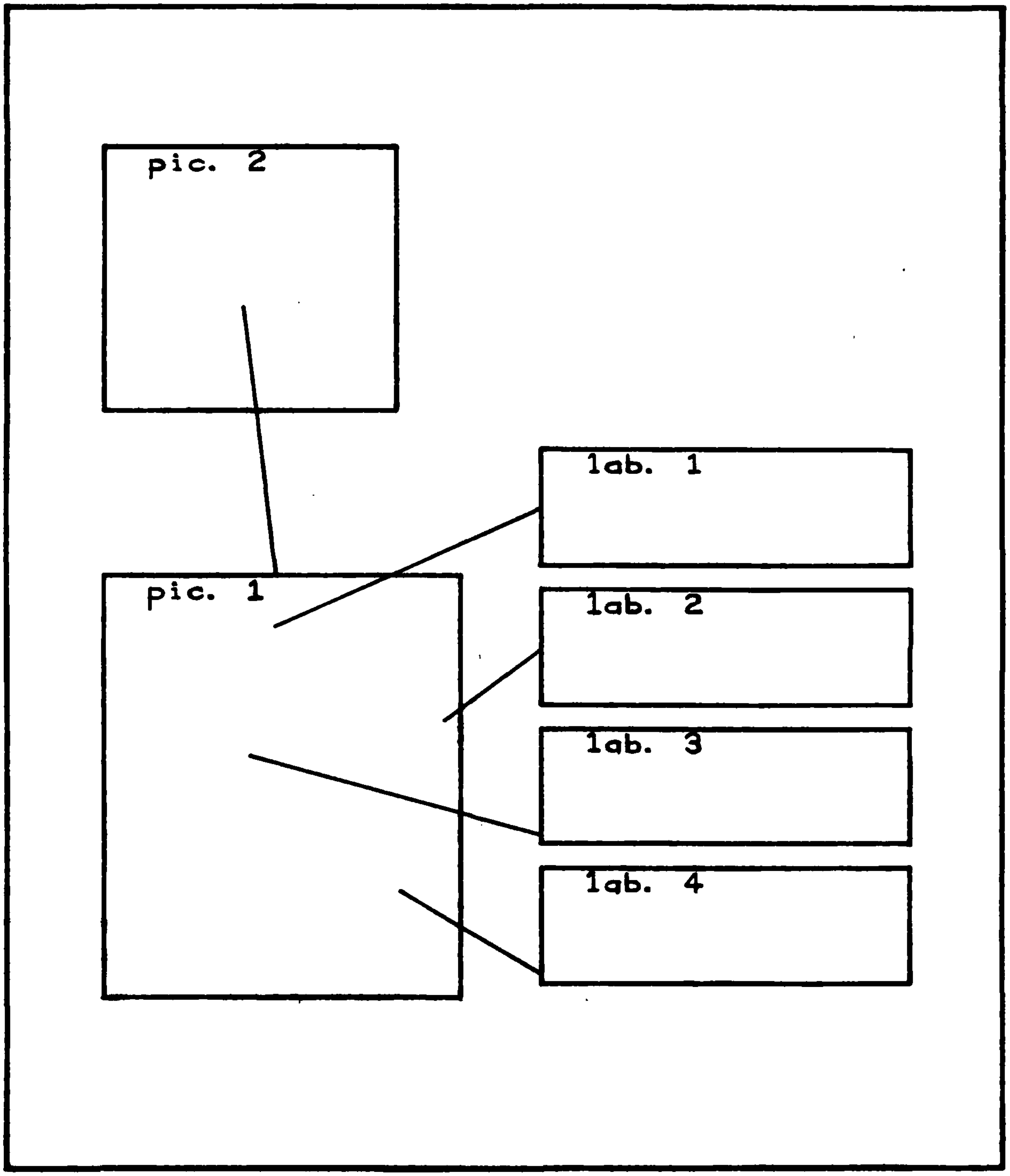
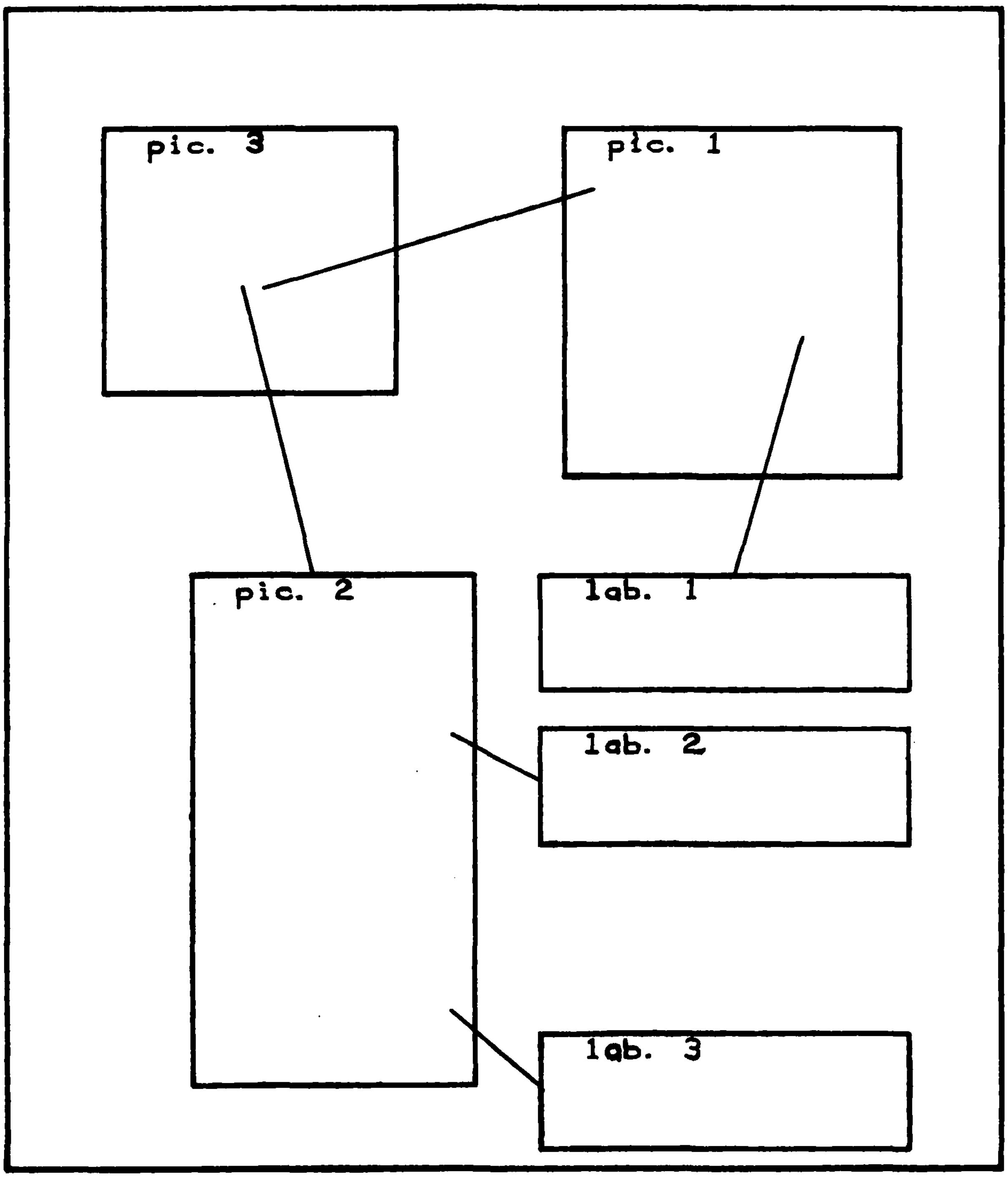
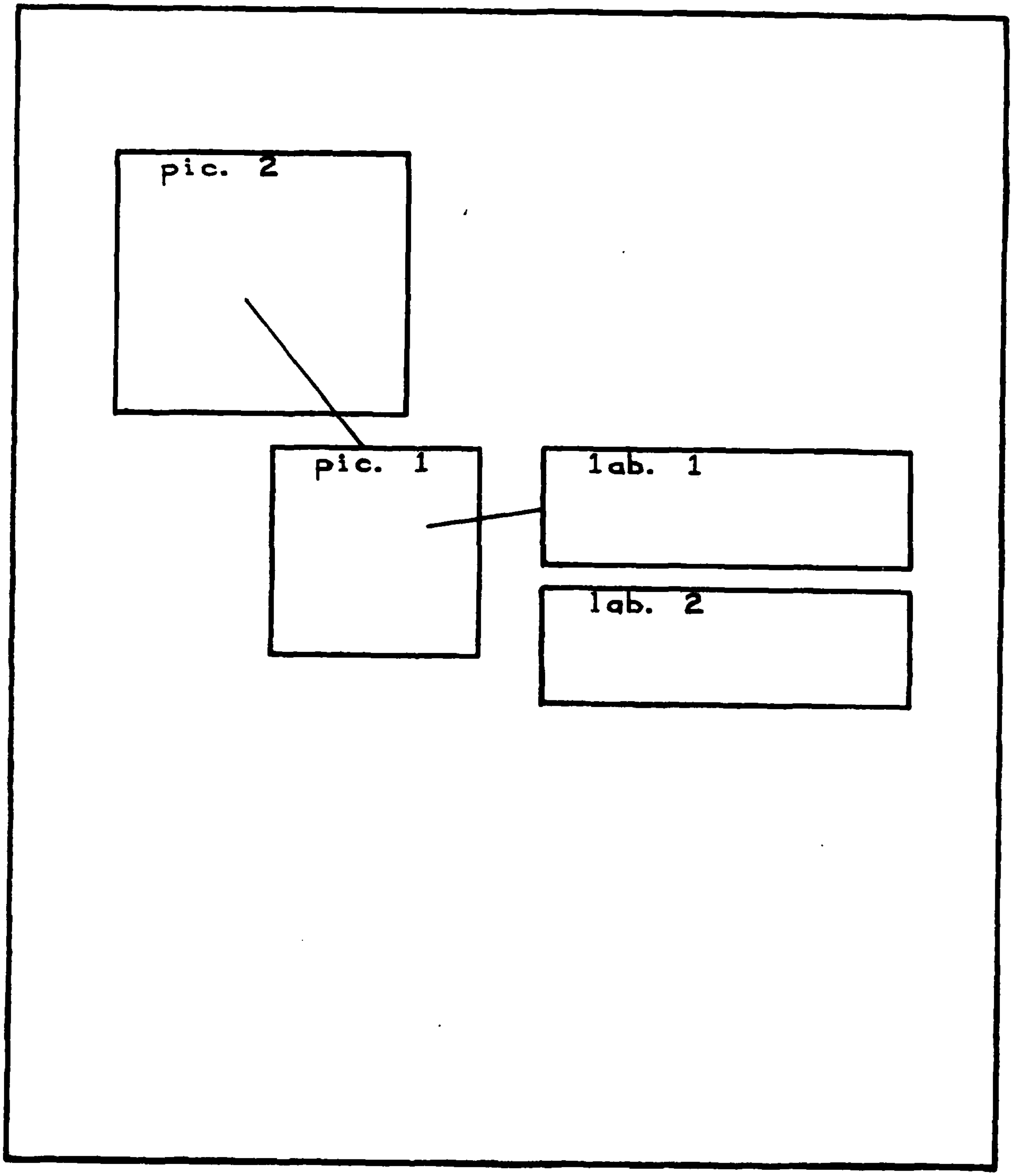
lab. 1
lab. 2
pic. 1


pic. 2
pic. 1
lab. 1
lab. 2
lab. 3
lab. 4


pic. 2
lab. 1
pic. 1
lab. 2
lab. 3
lab. 4


pic. 3
pic. 1
pic. 2
lab. 1
lab. 2
lab. 3


pic. 2
pic. 1
lab. 1
lab. 2

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